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A PRODUCTION ENGINEERING MEASURE FOR 2 L BAND SOLID STATE MICRO--ETC(U)
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A PRODUCTION ENGINEERING MEASURE

FOR TWO L BAND SOLID STATE

MICROWAVE FREQUENCY SOURCES

See 1473 p V

QUARTERLY REPORT NO. 2

COVERING THE PERIOD 30 AUGUST TO 30 NOVEMBER 1976

PREPARED UNDER CONTRACT DAAB07-76-C-0026

FOR

COMMUNICATIONS SYSTEMS PROCUREMENT BRANCH

PROCUREMENT AND PRODUCTION DIRECTORATE

U.S. ARMY ELECTRONICS COMMAND

FORT MONMOUTH, NJ 07703

BY

ROCKWELL INTERNATIONAL

HYBRID MICROELECTRONICS DIV.

1200 N. ALMA RD.

RICHARDSON, TX 75080

"This project has been accomplished as part of the US Army (Manufacturing and Technology) (Advance Production Engineering) Program which has as its objective the timely establishment of manufacturing processes, techniques or equipment to insure the efficient production of current or future defense programs."

A PRODUCTION ENGINEERING MEASURE

FOR TWO L BAND SOLID STATE

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QUARTERLY REPORT NO. 2

COVERING THE PERIOD 30 AUGUST TO 30 NOVEMBER 1976

PREPARED UNDER CONTRACT DAAB07-76-C-0076

MANUFACTURING METHODS AND TECHNOLOGY ENGINEERING PROGRAM

BY

COLLINS RADIO GROUP

HYBRID MICROELECTRONICS DIV.

1200 N. ALMA RD.

RICHARDSON, TX 75080

WRITTEN BY: JEROME K. MCCOY

ABSTRACT

This report describes the specifications and approach, details the work completed in the design and fabrication of two L Band solid state frequency sources, and describes the progress made towards an eventual high rate production demonstration of these two circuits. These two circuits are a Modulator/Transmitter for Radiosonde applications and an FM Source.

The second set of engineering samples have been completed, and performance data is available.

Some of the characteristics of thick film that will determine the eventual utility of this technology at microwave frequencies are Q and line definition. These parameters and others will be examined in the materials evaluation portion of the ECOM program. This report describes the work completed to date in this area of investigation.

Plans have been formulated for the third set of engineering samples.

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SECTION 1

INTRODUCTION

1.1 PURPOSE

The purpose of this contract is to establish the design and producibility of two microwave frequency sources, to improve the ability to produce the component or process and to compile data for production of these two sources on the basis of existing plant capacity. The characteristics of the devices are briefly described as follows:

A. Radiosonde Modulator/Transmitter

1.	Frequency	1680 ± 20 MHz
2.	Power Output	65 mW
3.	Modulation	100% AM 0 to 1835 Hz
4.	Frequency Stability (-70°C to +70°C)	± 2 MHz

B. FM Source

1.	Frequency	1375 ± 25 MHz
2.	Power Output	500 mW
3.	Modulation	FM 0 to 1 MHz rate
4.	Tuning Linearity (50 MHz Bandwidth)	± 2%

Further, it is a goal of this program to investigate the application of thick film technology in microwave integrated circuits and to determine the processes and materials required for low cost, high volume production.

1.2 REQUIREMENTS

The requirements of this contract are:

1. Deliver 40 engineering samples of each circuit type.

2. Test and deliver, with test reports, 50 confirmatory samples of each circuit type.
3. Establish a pilot production line and fabricate 500 units of each type at a rate of 4000 units per month.
4. Prepare technical data and reports.
5. Determine the requirements and plans to support a production rate of 40,000 units per month.

1.3 GLOSSARY

Radiosonde - A miniature radio transmitter with instruments attached, which is carried by an unmanned balloon to a height of 105,000 ft and dropped by parachute, for broadcasting by means of precise tone signals, information on humidity and temperature.

MIC - Microwave integrated circuit

TBD - To be determined

RF - Radio frequency

Q - A measure of the relationship between stored energy and the rate of dissipation in certain elements, structures or materials

TC Bond - Thermo compression bond

PEM - Production engineering measures

MM&T - Manufacturing Methods and Technology

FRIT - Melted-glass composition, ground up and used in thick film compositions, that melts upon firing to give adhesion to the substrate.

MESH SIZE - The number of openings per lineal inch in a screen. A 200-mesh screen has 200 openings per lineal inch, 40,000 openings per square inch.

SECTION 2

NARRATIVE AND DATA

2.1 RADIOSONDE MODULATOR/TRANSMITTER

2.1.1 Description of the Device

The Radiosonde Modulator/Transmitter consisting of a mechanically tuned L-Band thick film oscillator, a thick film hybrid modulator, a negative voltage regulator and a discone antenna comprises 90% of the electronics of Atmospheric Meteorological Probes. The modulator generates and shapes pulses which 100% amplitude modulate an RF carrier. The pulse repetition rate of the modulator which varies from 0 to 950 Hz, is determined by the resistance of the temperature and humidity sensors. The modulator also generates identification frequencies of 1395 Hz, 1630 Hz and 1835 Hz and a reference frequency of 950 Hz. The data, identification frequencies and reference frequency is sequentially telemetered to the ground station when it can be automatically processed. The oscillator can be tuned from 1660 MHz to 1700 MHz and delivers a minimum of 65 mW across the operating band under all operating conditions. The RF signal is fed into a discone antenna having an input impedance of 50 ohms. After testing the entire transmitter is assembled in a protective dielectric housing.

The requirements of the radiosonde are summarized in Table 1.

Table 1. Summary of Requirements for the Radiosonde Modulator/Transmitter Module

PARAMETER	VALUE	UNITS
Frequency (Mechanically Tunable)	1680±20	MHz
Power Output (Coaxial Output)	65 min.	mW
Frequency Stability (vs Temperature)	4 max.	MHz
Frequency Shift with Modulation	150 max.	kHz
Pulse Modulation Rates		
Meteorological Data	25 to 950	pps
Identifiers	1395±115	pps
	1630±115	pps
	1835±75	pps
Reference	950±50	pps
Super-regeneration	None	-
Sensor Base Current	75 max.	μA
Transfer characteristic	per para. 3.2.1.12 of SCS-408A	
Weight	150 max.	gms
Operating Conditions		
Supply Voltage	-20 to -30	Volts
	-24 nom.	Volts
Temperature	-70 to +70	°C
Altitude	105,000	ft
Current	100 max.	ma
Pulse Width	60±20	μsec

2.1.2 Design Considerations

Tuning Range - The tuning range for the oscillators in the first engineering samples averaged 40 MHz, ranging from 1-92 MHz. Related to this problem was a high oscillator center frequency which ranged from 1690 to 1760 MHz. These two parameters, center frequency and tuning range are functions of the tuning capacitance at the end of the stabilizer line. In the units representing the second engineering samples, the effective area of the tuning screw has been increased from 2400 sq. mils to 5000 sq. mils. The effect of this was a 2.5:1 increase in the tuning range, which enabled all the oscillators to be tuned through the 1660-1700 MHz operating range.

Increasing the tuning screw size presented an alignment problem in the oscillator assembly. The tuning screw with a working diameter of 80 mils must fit through a substrate hole 96 $\pm$ 3 mils. With a misalignment of 7 mils, the tuning screw would catch the edge of the substrate hole. This problem was handled by attaching the tuning assembly to the base plate with a high temperature solder before soldering the substrate down with lower temperature solder. Placing the substrate onto the base plate and over the tuning screw so that the screw extends through the hole during the soldering process ensures exact alignment of the substrate with the tuning screw.

Modulator Transfer Characteristic - The modulator transfer characteristic is a relationship between the resistance of the temperature or humidity sensors and the modulation frequency. This relationship, as defined by contract paragraph 3.2.1.12, is expressed by the following equation:

$$\text{Modulation Frequency} = \frac{1.1184 \times 10^8}{Rs + 1.1788 \times 10^5}$$

where Rs = Sensor resistance

The modulator hybrid used in the radiosonde contains an astable multivibrator which generates this relationship. In terms of a multivibrator, the frequency can be determined from the period by

$$f = \frac{1}{T} = \frac{1}{T_1 + T_2}$$

where T_1 = ON pulse time

T_2 = OFF pulse time

The OFF pulse time is held a constant 44 μsec. (spec is 60 ± 20 μsec). The ON pulse time can be calculated from the relationship:

$$T_2 = (R17 + Rs)\ C\ \ln(k)$$

where C = .012 μfd.
k = adjustable voltage ratio set by a 10K ohm trimpot attached to the modulator board.

If k is adjusted such that $C \cdot \ln(k)$ is always constant, then

$$f = \frac{1}{44\ \mu\text{sec} + (R17 + Rs) \circ \text{Constant}}$$

and the shape of the transfer characteristic is controlled by R17 only.

To determine the correct value of R17, a modulator board was built with R17 bypassed and replaced by a decade resistance box. By iterating the resistance value and plotting the resulting % error from the nominal modulator curve, the optimum value and tolerance can be determined. The results are plotted in Figure 1 and show an optimum value for R17 is 108k with a tolerance of ± 1%. This analysis is verified by the results of the tests on the ten engineering samples just shipped in which eight of ten modulators met the specification.

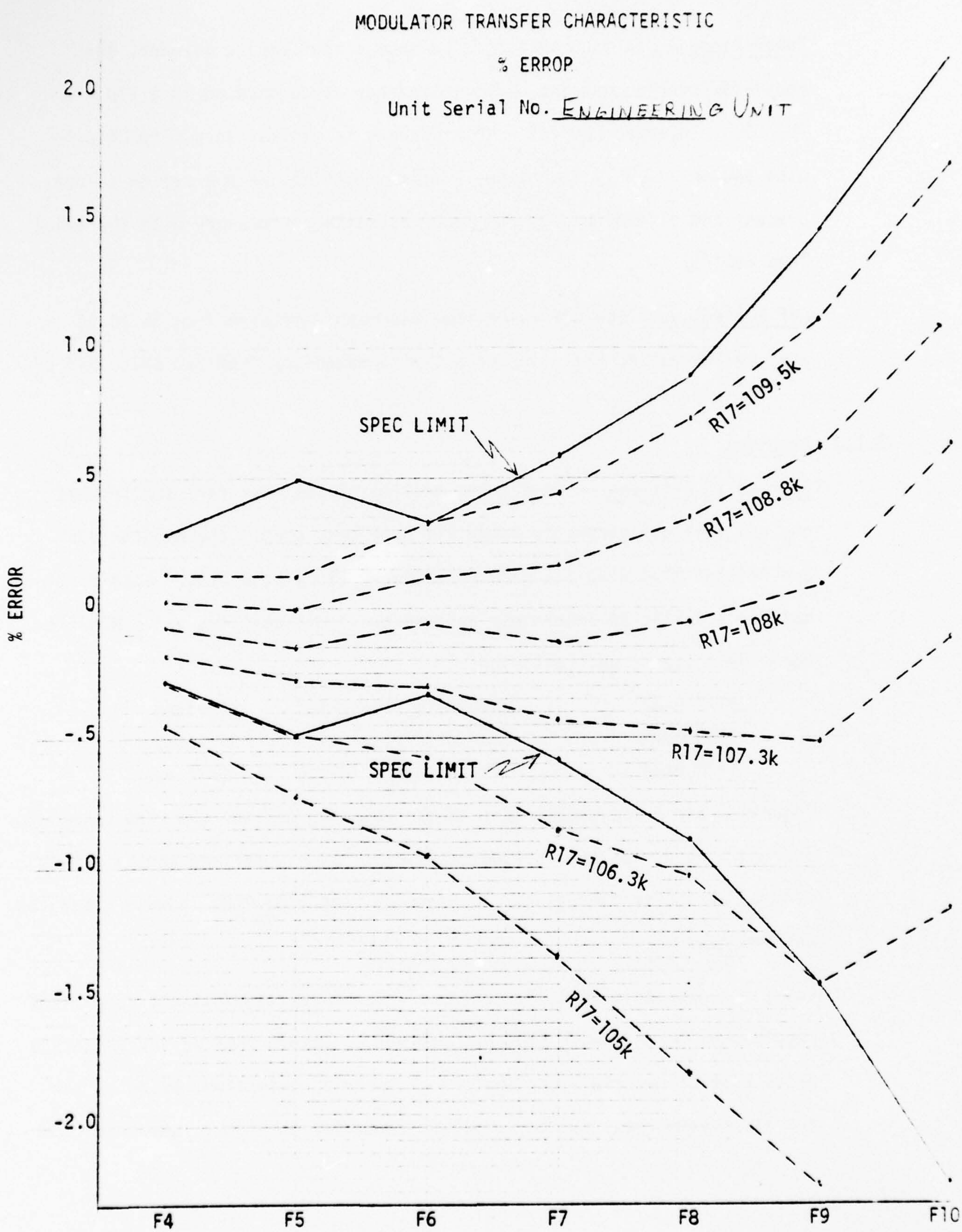

MODULATOR TRANSFER CHARACTERISTIC
% ERROR
Unit Serial No. ENGINEERING UNIT
2.0
1.5
1.0
.5
0
-.5
-1.0
-1.5
-2.0
% ERROR
SPEC LIMIT
R17=109.5k
R17=108.8k
R17=108k
R17=107.3k
SPEC LIMIT
R17=106.3k
R17=105k
F4
F5
F6
F7
F8
F9
F10

FIGURE 1

Zener Diode - In four units of the second engineering samples, the modulator hybrid contains a 5.6 volt zener diode mounted in a LID (Leadless Inverted Device). This package is similar to a flip chip in size and in assembly technique. It is compatible with a reflow solder process and eliminates several labor operations necessary with the axial lead device.

OFF Pulse Time - The off pulse time has been increased from 35 to 44 µsec by increasing the value of a timing capacitor from 510 pf to 560 pf.

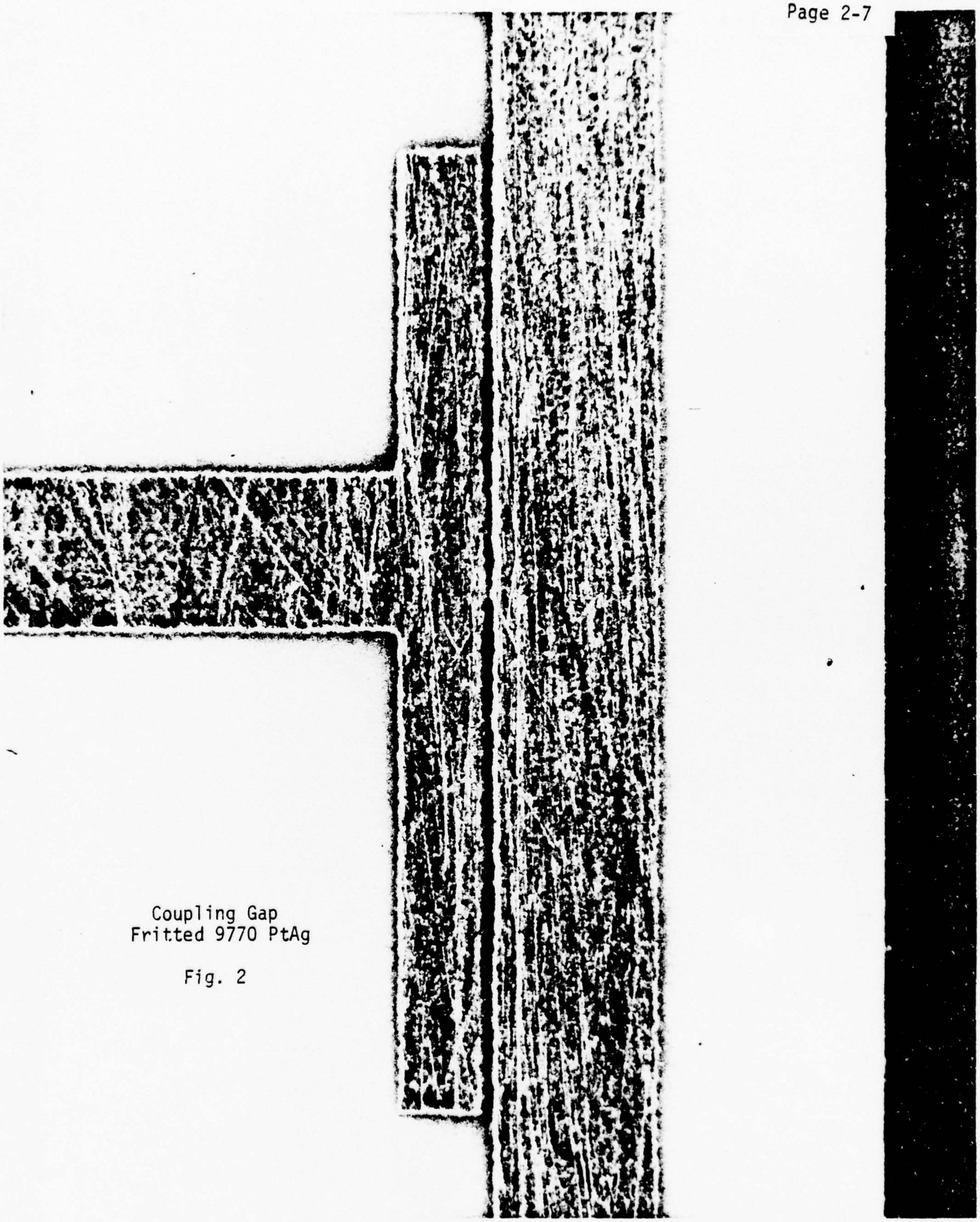
2.1.3 Problems

Fritted VS Fritless - In the engineering builds thus far, two fritted and one fritless conductor materials have been used. These materials are fritted 9770 PtAg and 9308 PdAg and fritless 1130 PtAg. Both fritted materials failed to accurately produce the 4 mil coupling gap. Manufactures data states the following:

9770 PtAg	7-10 mils resolution	Fritted
9308 PdAg	5-8 mils resolution	Fritted
1130 PtAg	5 mils resolution	Fritless

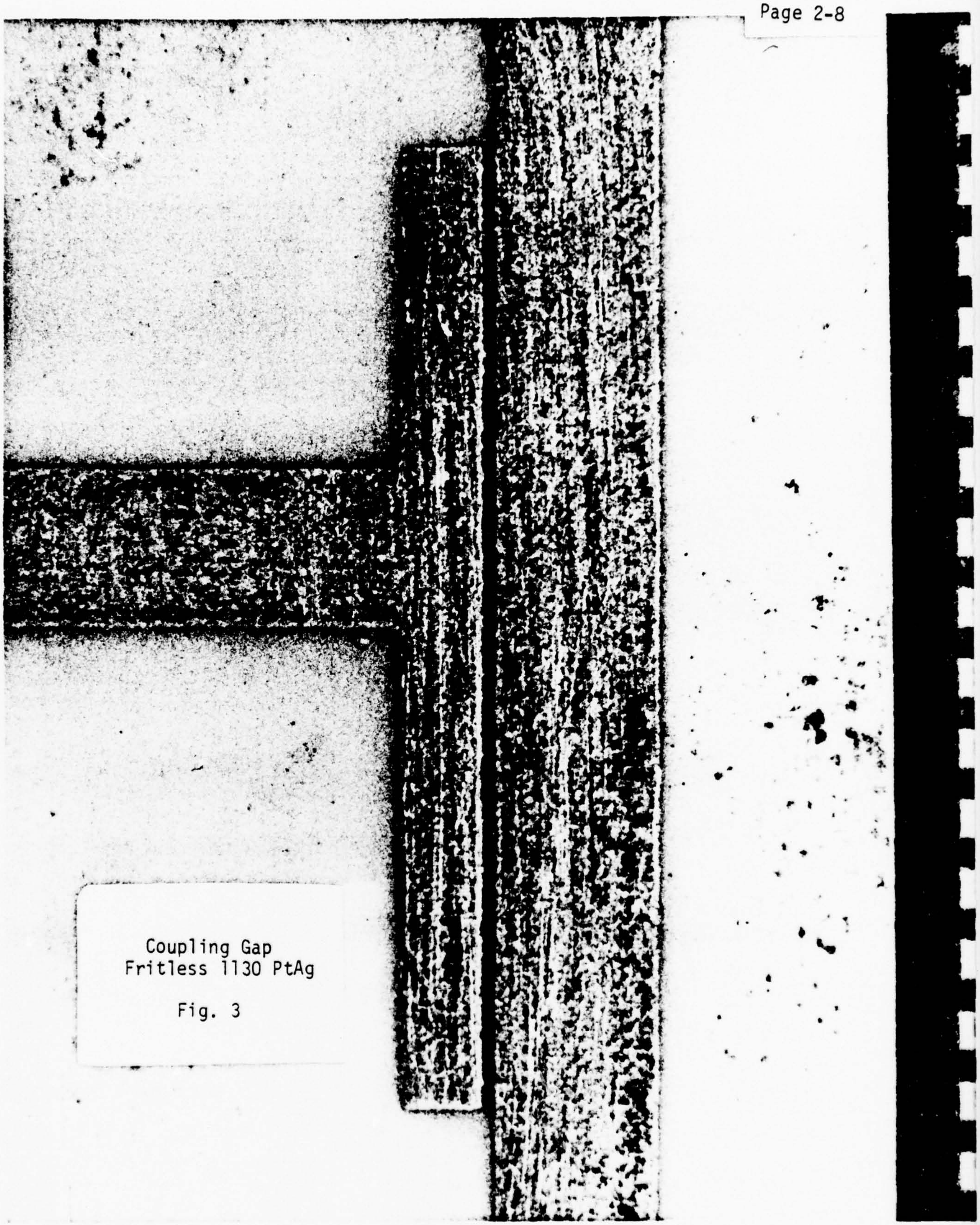
Figures 2 and 3 are photographs of the coupling gap for the PtAg materials. The gap formed with the fritted material is poorly defined and is almost bridged across at one point. In contrast, the 1130 PtAg shows a clean and uniform gap.

Collins Radio feels that the intension of the fritted-fritless comparison requirement in this ECOM MM&T program was to ensure that we investigate a broad base of materials and that final material selection, based on the overall system requirements, would be conducive to high volume production.



Coupling Gap
Fritted 9770 PtAg

Fig. 2



Coupling Gap
Fritless 1130 PtAg

Fig. 3

Considering the results of the Q measurements (see section 2.3) on the PtAg and PdAg materials and considering what we have learned about line resolution and fritted materials, we feel that the intent of the contract has been satisfied for the Radiosonde Modulator/Transmitter. Therefore, the 1130 fritless PtAg has been selected for use in Unit A, and the fritted-fritless comparison will be dropped for this portion of the contract.

Substrate Breakage - The modulator hybrid is fabricated on a 25 mil alumina substrate, approximately 1 inch square. It is epoxy mounted directly to the radiosonde baseplate, using a nonconductive black epoxy (Ablestik 161-3).

As reported in the Second Engineering Test Report, two of the four units temperature tested developed cracks in the substrate. Most likely, the cracks developed during the final assembly of the radiosonde when, in handling the units, the base plates were flexed, causing the substrate to crack. Expansion during temperature testing merely completed the cracking process. A less rigid epoxy such as RTV may be the solution to this problem.

2.1.4 Test Results

Table 2 is a summary of the test results on the Radiosonde Modulator/Transmitter second engineering samples. Note that the output power, current, center frequency and tuning range are in spec. Frequency stability was only measured on two units because of the substrate cracking problem.

TABLE 2

Radiosonde

Second Engineering Samples

Test Data Summary

	Unit #	Matl.	Center Freq. (GHz)	Tuning Range (MHz)	ΔFreq/ΔTemp (MHz)	Power Output (mW)	Current (mA)
FRITTED	11	PtAg	1.68	112	1.7	107	90
	12	PtAg	1.68	126		99	81
	19	PtAg	1.68	105		97	90
	Average		1.68	114		101	87
FRITLESS	13	PtAg	1.68	125		100	88
	14	PtAg	1.68	99		95	85
	15	PtAg	1.68	140		112	91
	16	PtAg	1.68	106		100	88
	17	PtAg	1.68	107		104	88
	18	PtAg	1.68	77	3.9	118	81
	20	PtAg	1.68	95		107	88
	Average		1.68	107		105	87
	Specification		1.680	40 Min.	4 Max.	65 Min.	100 Max.

2.2 FM SOURCE

2.2.1 Description of the Device

The FM Source is a thick film microwave integrated circuit intended for use as a linear frequency modulated transmitter in applications requiring a rugged, low cost, lightweight device. It consists of a varactor tuned transistor oscillator followed by a transistor power amplifier stage. The oscillator operates at a fixed frequency of 1375 ±25 MHz and delivers a minimum of 500 mw into a 50 ohm load. The unit is capable of being frequency modulated at any rate up to 1 MHz by application of a signal on a designated input lead. Total frequency deviation is 50 MHz minimum. The unit is housed in a rugged hermetic structure capable of withstanding severe environmental stress.

The requirements for the FM Source are summarized in Table 3.

2.2.2 Design Considerations

PA Input Impedance - The power amplifier is a 2N5108 transistor operated Class C. The details of the initial design were stated in the first quarterly report. It was observed during the build of the first ten units that the input impedance of the amplifier was considerably different than what was expected. Typical VSWRs were 3:1 to 5:1. Additional capacitance at the input to the transistor improved the VSWR but introduced a resonance that was characterized by a discontinuity in the linearity curve. Twice during September and October, the input impedance to the transistor was measured with the output matched with the present network. The first measurement was made by matching the input to 50 ohms with a double stub tuner at a given frequency. Then by measuring the input impedance of the double stub tuner and computing

Table 3

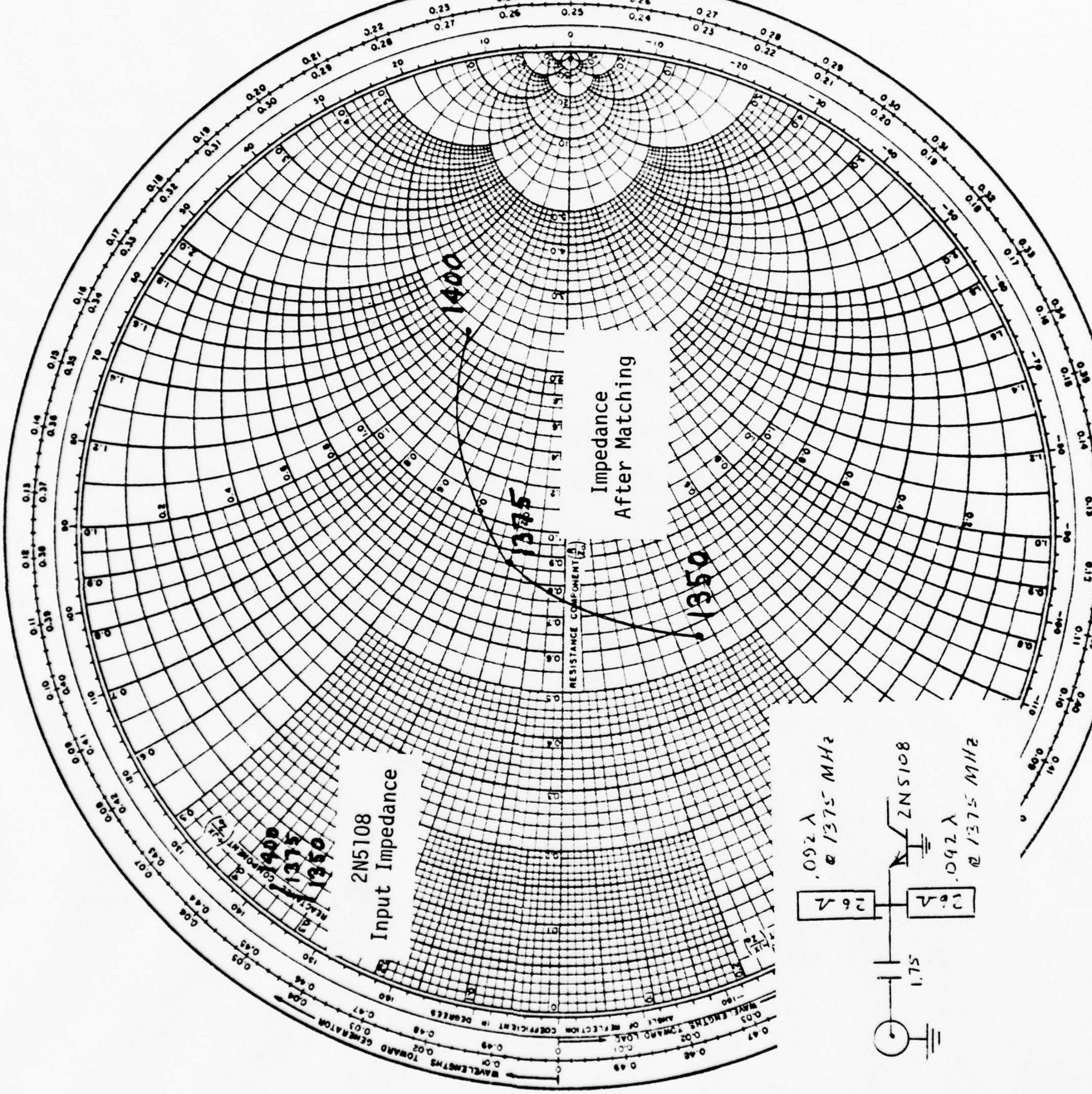
Summary of Requirements for the FM Source

PARAMETER	VALUE	UNITS
RF Frequency	1375 ± 25	MHz
Power Output	500 Min.	mW
Power Variation over Frequency Range	1 Max.	dB
Modulation		
Type	FM	
Deviation	± 25 Min.	MHz
Tuning Voltage	30	Volts p-p
Input Impedance	1000 Min.	ohms
Deviation from constant tuning slope	± 2 Max.	%
Input Voltage @ Center Frequency	15 ± 5	Volts
Operating Conditions		
Supply Voltage	24 ± .25	Volts
Current @ 24 VDC	175 Max.	ma
Temperature	-40 to + 70	°C
Shock	150 (for 11 mscc)	g
Altitude	50,000	ft
Weight	65	grams
AM Noise	-100	dBc
FM Noise	-60	dBc
Frequency Turn On Stability	± 2.5	MHz
Power Turn On Stability	±10	%

the complex conjugate, the transistors input impedance can be calculated. This data was later found to be incorrect because of errors introduced by the double stub tuner, and the network that was designed, based on this data, was grossly in error.

A direct measurement of the transistor was made without a double stub tuner by driving the transistor from a 1 Watt source. It took 600-700 mw of power to drive the transistor to full output power. Using a high power reflection test head and network analyzer, an accurate measurement of the input impedance was obtained. This data is presented in Figure 4 . Unfortunately, this information came too late to incorporate a new matching network into the second engineering samples. Figure 4 also details the theoretical results of a matching network based on the latest input impedance data. This network will be incorporated into the third engineering samples.

Structural Analysis of Housing - *The device has to withstand a half-sine* shock pulse at 30,000g (Peak) for a period of 6 MS. The following calculations will show that resultant dynamic stresses do not exceed the yield point to cause permanent deformation or cracking of ceramic substrate. Similar calculations have been performed by RCA on a previous contract as presented in Appendix A of Quarterly Report No. 6, (ECR-428-6) on contract No. DAAB05-72-C-5830. This format is followed since the information is presented in suitable form for this presentation. Refer to Figure A for a sketch of the unit.



1400
1375
1350
Impedance After Matching
2N5108 Input Impedance
2N5108
.092 λ @ 1375 MHz
26 Ω
1.75

FIGURE 4

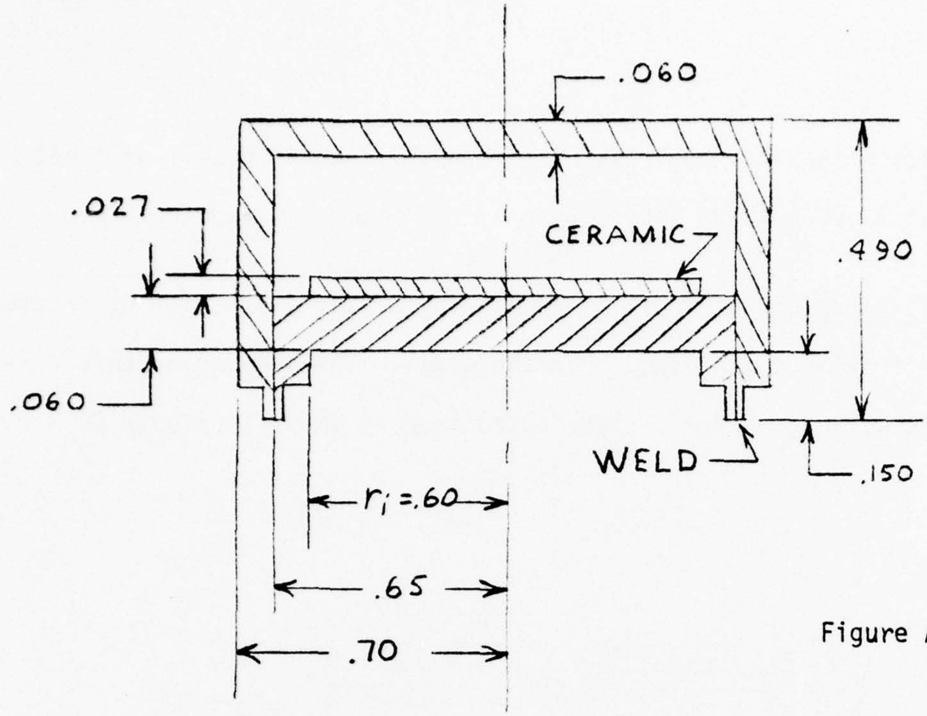


Figure A

The structure is AISI 410 stainless steel heat treated to Rockwell C-41.

Tensile Strength	117,500 psi
Yield Strength	103,700 psi
Modulus of Elasticity, E	$29\text{X}10^6$ psi
Density, ρ	.28 lb/in^3
Poisson's Ratio, μ	.30

Summary of Analysis:

<u>Outer Cup</u>

Static deflection δ_{st} = $8.17\text{X}10^{-8}$ inch

Dynamic deflection δ_D = .0025 inch, f_n=11,495 Hz

Dynamic maximum bending stress

σ_{MAX} = 44,360 psi

<u>Inner Cup</u>

Static deflection δ_{st} = $7.4\text{X}10^{-8}$ inch

Dynamic deflection δ_D = 0.0022 inch, f_n=10,610 Hz

Dynamic maximum bending stress

σ_{MAX} = 37,800 psi

Ceramic

Deflection required to break ceramic=.0051 inch. Ceramic will not fail at 30,000g since inner cup only deflected .0022 inch.

Static Deflection of Outer Cup - The bending of the plate will be treated as a flat circular plate clamped at the edges. The bending of this circular plate with a uniformly distributed load is shown in Figure B.

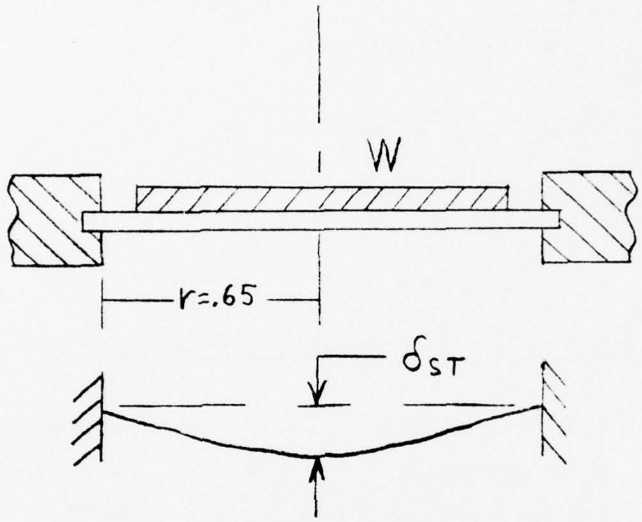


Figure B

The static deflection at the center is found by:[1]

$$\delta_{st} = .1875 \bullet \frac{Wr^4(1-\mu^2)}{Eh^3} = .1875 \bullet \frac{r^4\rho(1-\mu^2)}{Eh^2}$$

where h is the thickness

$$\delta_{st} = \frac{.1875(.65)^4\ (.28)\ [i - (.3)^2]}{(29X10^6)\ (.06)^2}$$

$$= 8.17X10^{-8} \text{ inches}$$

(1) Timoshenko, Strength of Materials, 3rd ed, pg.97

Natural Frequency of top plate:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_{st}}} \overset{(2)}{=} \frac{1}{2\pi}\sqrt{\frac{386}{8.17\text{X}10^{-8}}}$$

$$= 10{,}940 \text{ Hz}$$

For a half-sine shock pulse of 30,000g peak and a duration of 6 msec, the transmissibility can be determined. The transmissibility is defined as the ratio of the dynamic output to the dynamic input. For a half-sine shock pulse, the transmissibility can be expressed as shown in Figure C.

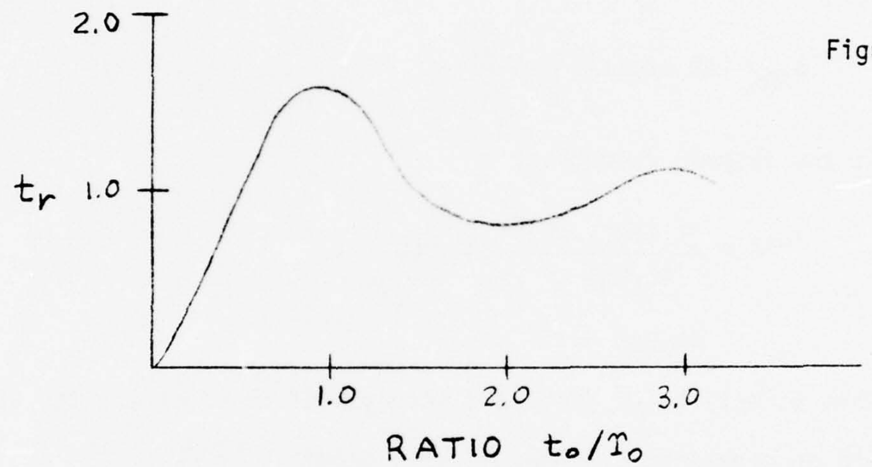


Figure C

$$\text{Ratio } t_o/T_o = \frac{\text{Shock pulse time duration}}{\text{Natural period of system}}$$

Natural period of the system, $T_o = \dfrac{1}{f_n}$

$$T_o = \frac{1}{10{,}940} = 9.14\text{X}10^{-5} \text{ 1/sec}$$

$$\text{Ratio } t_o/T_o = \frac{6\text{X}10^{-3}}{9.14\text{X}10^{-5}} = 65.6$$

(2) Morrill, Mechanical Vibrations, pg. 45

The ratio of the shock period to the natural period of the system is very high such that the transmissibility is equal to one. Thus the dynamic outputs will be 30,000 times the static inputs.

Dynamic Deflection (Outer Cup)

$$\delta_D = 8.17 X 10^{-8} \quad X \quad 30{,}000$$

$$= .0025 \text{ in.}$$

Dynamic Maximum Bending Stress - The maximum bending stresses of the clamped circular cover occur at the edges.

(3)

$$\sigma_{MAX} \text{ (at edges)} = \frac{3Wr^2}{4h^2} = \frac{3\rho r^2}{4h}$$

at the dynamic conditions

$$\sigma_{MAX} = \frac{3(.28)\ (.65)^2}{4(.06)}\ (30{,}000)$$

$$= 44{,}360 \text{ psi}$$

This is well below the yield strength of the heat treated stainless steel and no permanent deformation will occur.

Static Deflection (Inner Cup)

The inner cup will also bend as a clamped circular plate. The static deflection will be:

$$\delta_{st} = .1875 \bullet \frac{Wr^4(1-W^2)}{Eh^3} = \frac{(.1875)\ (.021)\ (.60)^4\ (1-(.3)^2)}{(29X10^6)\ (.06)^3}$$

$$= 7.4 \text{ X } 10^{-8} \text{ inch}$$

(3) Timoshenko, Strength of Materials, 3rd ed, p. 97

The Natural Frequency of the Inner Cup:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{386}{7.4X10^{-8}}} = 11{,}495 \text{ Hz}$$

Dynamic Deflection of Inner Cup:

$$t_r = 1.0$$

$$\delta_D = (7.40X10^{-8})\ (30{,}000)$$

$$= .0022 \text{ inch}$$

Dynamic Maximum Bending Stress - The maximum stresses due to bending will occur at the inner edges.

$$\sigma_{MAX} \text{ (at inner edge) } = \frac{3(.28)\ (.60)^2\ (30{,}000)}{4(.06)}$$

$$= 37{,}800 \text{ psi}$$

This is well below the yield point.

Deflection Required to Break Ceramic - The ceramic substrate (99.5% Al_2O_3) is soldered to the flat surface of the inner cup and will bend circularly as the inner cup bends. The edges of the ceramic are not constrained as the clamped plate, and by applying the theory of circular plates, simply supported on the edges, the maximum deflection the ceramic substrate can have before reaching its tensile strength (30,000 psi) is expressed by:

$$\delta_c = 1/2 \left(\frac{5 + \mu}{1 + \mu}\right) \left(\frac{1 - \mu^2}{3 + \mu}\right) \left(\frac{\sigma_{MAX} R^2}{Eh}\right) \qquad (4)$$

(4) Timoshenko, pg 98

where the properties of the ceramic are:

$E = 50X10^6$ psi

$\mu = .21$

$h = .027$ inch

$\sigma = 30{,}000$ psi

$$\delta_c = 1/2 \left(\frac{5 + .21}{1 + .21}\right) \left(\frac{1 - (.21)^2}{3 + .21}\right) \left(\frac{30{,}000(.60)^2}{(50X10^6)\ (.027)}\right)$$

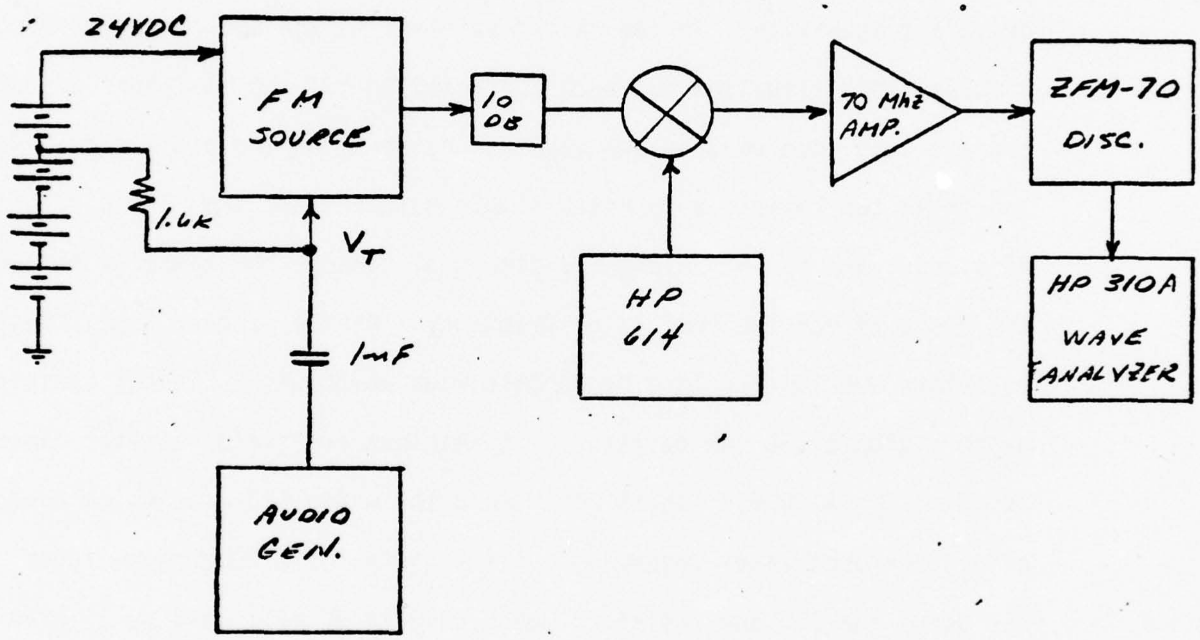
$$= .0051 \text{ inch}$$

Since the inner plate to which the substrate is soldered is only deflected .0022 inch for 30,000g, the ceramic will not fail.

2.2.3 Work Performed

Resistor Fabrication - A set of guidelines to follow in the design and layout of thick film resistors that is based on processing capabilities and material characteristics has been established. In the initial design, the nine resistors on the FM Source did not conform to these guidelines in that they did not meet the minimum dimension size. Consequently, the as-fired resistor values varied considerably. If this situation were to exist in the circuit in high volume production, it would reduce the overall yield, complicate the trimming procedure and degrade resistor post-trim drift and stability. In the units representing the second engineering samples, this situation has been corrected in all the resistors except the two that form part of the feedback network for the oscillator. Adjusting these two resistors is not a simple matter since they are part of the RF circuit and to increase their size would change the capacity to ground and could affect the oscillator frequency. At the present time, these resistors are 10 mils long by 40 mils wide which with a 1kΩ/□ resistor paste yields a 250 ohm resistor. The minimum preferred resistor dimension is 30 mils. A 30 mil length would make the width 120 mils which could affect the oscillator frequency. Alternately, if a 300Ω/□ resistor paste was used, the 250 ohm resistors would only be 30 mils long by 36 mils wide. However, this would involve an additional screening operation.

FM Noise Test - FM noise measurements were made on the FM Source, using the heterodyne-discriminator method shown in Figure 5. Carrier noise and 200 KHz deviation is used as a reference for comparison. Noise power is measured within a 1 KHz bandwidth via a HP310A frequency selective voltmeter which is tuned in 2 KHz increments from D.C. (carrier reference) to the 10 KHz offset frequency. A plot of the noise characteristics of a Collins engineering model is shown in Figure 6.



FM NOISE TEST SET UP

FIG 5

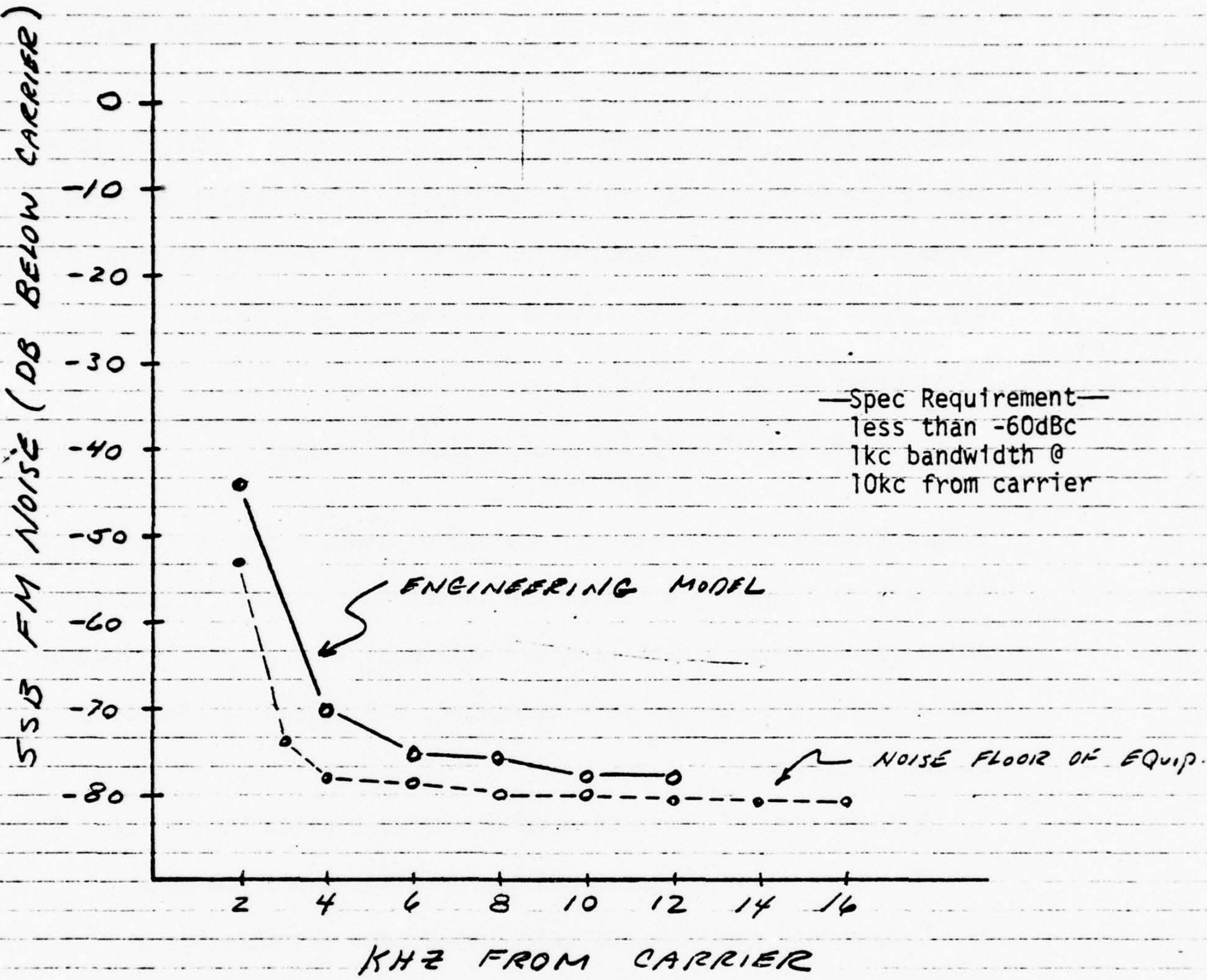

SSB FM NOISE (DB BELOW CARRIER)
0
-10
-20
-30
-40
-50
-60
-70
-80
—Spec Requirement—
less than -60dBc
1kc bandwidth @
10kc from carrier
ENGINEERING MODEL
NOISE FLOOR OF EQUIP.
2
4
6
8
10
12
14
16
KHZ FROM CARRIER

FIG 6

2.2.4 Test Results

Table 4 is a summary of the test results on the FM Sources which represented the second engineering samples. Data is at 25°C. Note that the output power, power variation and current are all in spec, but center frequency tuning voltage is not. This parameter, however, is easily adjusted by changing the ratio of a resitive voltage divider. Tool changes are in progress to correct this ratio.

First order linearity, defined by

$$\frac{\text{max. deviation from straight line}}{\text{Bandwidth}} \times 100\%$$

ranged from 2% to 9.6% with an average of 5.8%. This is contrary to the data on linearity given in the second test report (see appendix) which was based on a different definition of linearity. To further characterize and improve this parameter, the following efforts are planned or are in progress:

1. Optimization of PA input matching network as defined on page 2-14. This work is in progress, with promising results to date.
2. Independent computer characterization and optimization of oscillator.
3. Oscillator linearity VS loading test, using calibrated mismatch and line stretcher.
4. Increasing isolation between oscillator and PA by inclusion of a resistive pad. This work is being done in conjunction with the PA input impedance optimization.

TABLE 4

TEST DATA SUMMARY - FM SOURCE

	UNIT #	MIN PWR OUT (mw)	PWR VARIATION (db)	CURRENT (ma)	TUNING VOLTAGE @ 1375 MHz (Volts)	ΔVOLTS for 50 MHz DEVIATION
FRITTED	13	580	.32	154	12.07	.98
	14	690	.12	156	8.67	2.05
	16	570	.22	154	8.99	2.20
	17	640	.13	154	8.92	1.54
	20	605	.11	164	8.61	2.26
FRITLESS	11	630	.07	154	7.67	2.82
	12	565	.37	158	8.00	2.12
	15	660	.44	167	11.08	.54
	18	645	.10	148	8.24	1.71
	19	665	.22	164	8.47	1.92
	Specification	500	1	175	15 ± 5	

2.3 Materials Evaluation

2.3.1 Q Measurements - The Q or quality factor of a structure is an important factor when considering its use in electrical systems. A knowledge of the Q of a transmission line at microwave frequencies is useful in determining such parameters as oscillator stability and noise, filter frequency selectivity and line attenuation. For a transmission line or waveguide attenuation, the attenuation per unit length, α, is related to Q by

$$\alpha = \frac{27.3}{Q\,\lambda g} \quad \frac{dB}{length}$$

where λg = guide wavelength = $\dfrac{\lambda_o}{(\varepsilon_{eff})^{1/2}}$

λ_o = free space wavelength

The objective of our measurements is to determine the Q for several selected thick film conductors and compare it to that of standard thin film gold. From this data, we can determine: (1) the useful frequency range for thick film and (2) the most appropriate material for microwave applications. As in any material selection process, there are other parameters to consider such as adherence, bondability and cost. Final material selection will be based on the overall requirements of the system.

Measurement Technique - A reflection test was chosen because of the ease and simplicity of a one port measurement. The technique involves coupling into a resonate structure, in this case a half wave (or multiples of) microstrip resonator. The basic circuit is illustrated in Figure 7

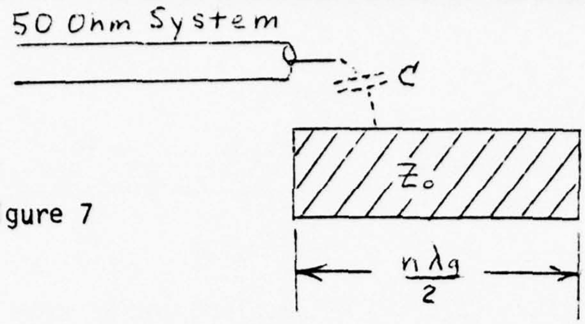


Figure 7

The coupling capacitor, C, which acts as a transformer to match the 50 ohm system impedance to the high equivalent parallel resistance of the resonator, is adjusted while monitoring a display of return loss versus frequency.

The value of C at which the return loss is maximized is termed critical coupling. This point is characterized by a very deep notch in the display (return loss typically > 30dB). Referring to Figure 8 , Q is calculated as follows:

$$a = \frac{|\rho_2|^2 - |\rho_3|^2}{|\rho_1|^2 - |\rho_2|^2}$$

where $\rho = 10 \exp (\text{Return Loss}/-20)$

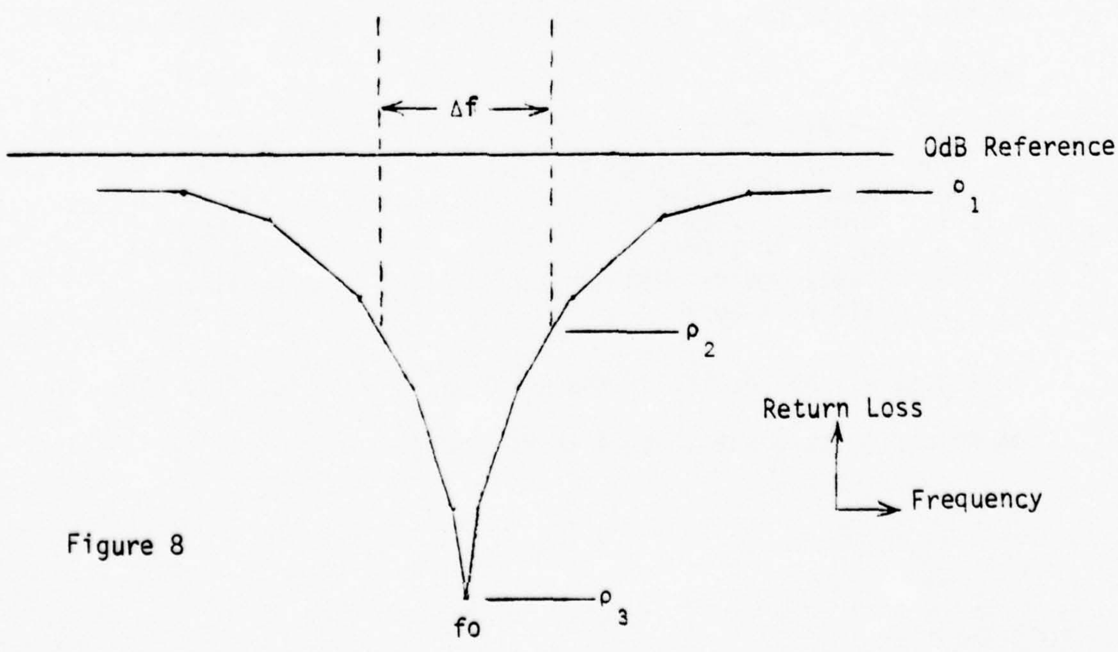


Figure 8

$$Q_{UL} = \text{Unloaded } Q = \frac{1 + |\rho_1|}{1 - |\rho_3|} \, a \, \frac{fo}{\Delta f}$$

If the data is taken at critical coupling and we make the assumptions that $\rho_1 = 1$ and $\rho_3 = 0$ and that the width of the notch is measured at the 10 dB points, or that $\rho_2 = .32$

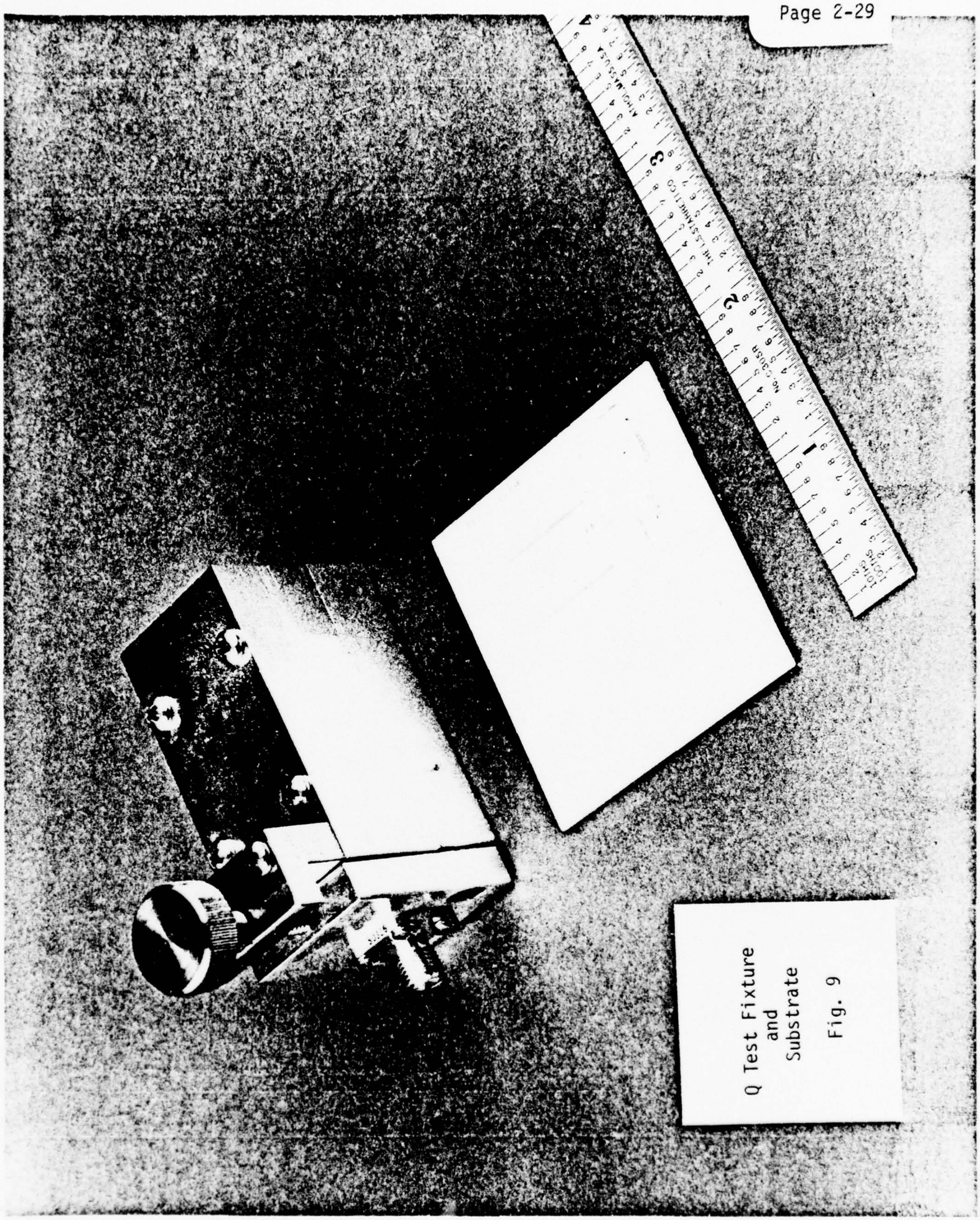
$$Q_{UL} = .666 \frac{fo}{\Delta f}$$

Figure 9 and 10 show the test fixture used for the measurements. The test fixture places a cavity, with a cutoff frequency of 18.5 GHz, around the resonator to prevent losses due to radiation and is silver plated to minimize conductor loss in the cavity walls. The coupling capacitance can be continuously adjusted, using the thumbwheel screw shown in Figure 9.

Q was measured at 2, 4 and 8 GHz. Attempts were made to obtain data at 16 GHz, but in this frequency range, the test fixture itself produced multiple resonances and radiated, making the data invalid. Note in Figure 9 the substrate and the 75, 50 and 20 ohm resonators screened on it. The following conductors were evaluated to determine their unloaded Q:

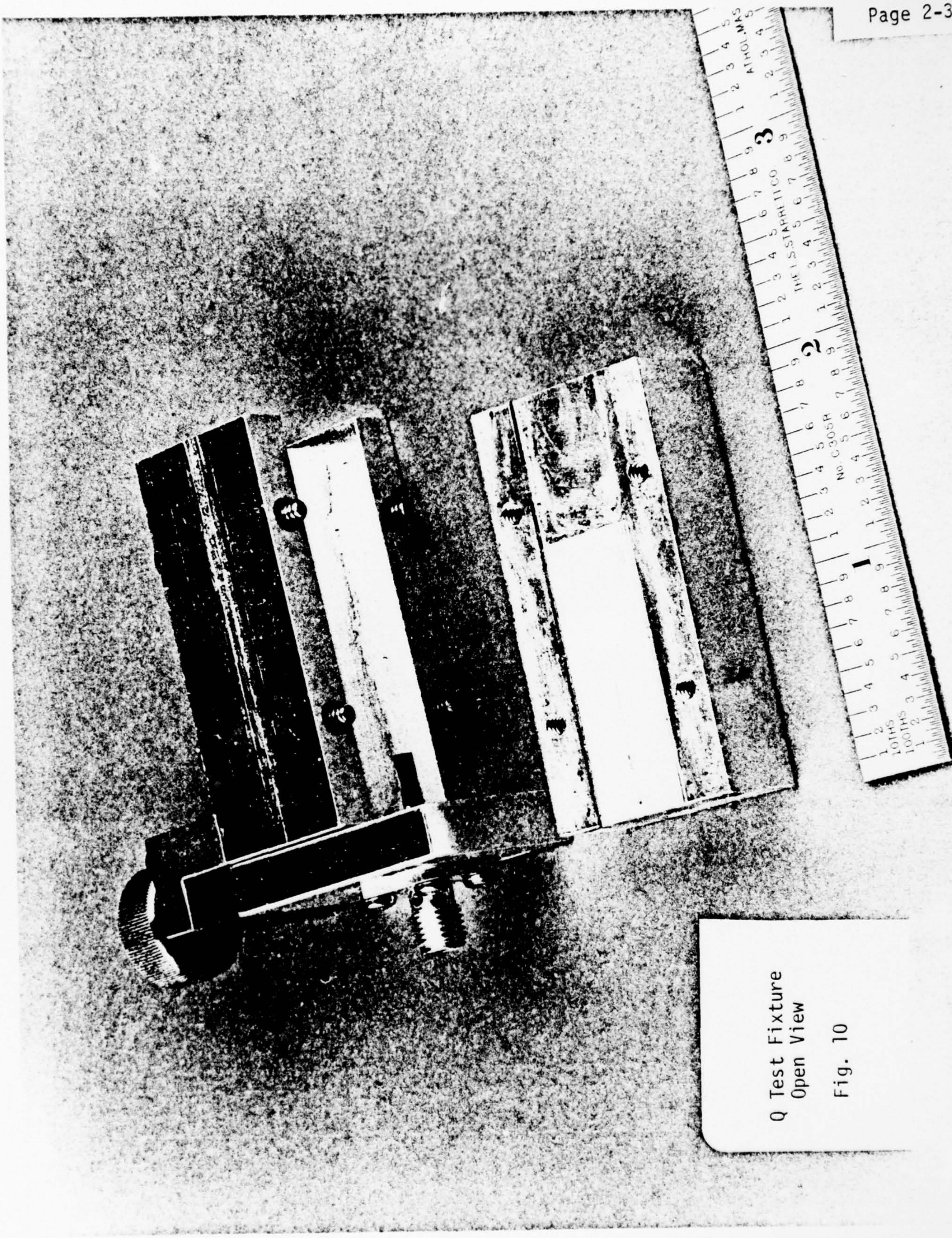
1.	Dupont 9770 PtAg	Fritted
2.	Electro-Oxide 1130 PtAg	Fritless
3.	Dupont 9308 PdAg	Fritted
4.	Cermalloy 7029 Cu	Fritted
5.	Dupont 9885 PtAu	Fritted
6.	Electro-Oxide 6990 Au	Fritless
7.	Thin Film Gold	250 μinch

Test Data - The results of the tests on six thick film conductors and on thin film gold are plotted in Figures 11 thru 16.



Q Test Fixture
and
Substrate

Fig. 9



Q Test Fixture
Open View

Fig. 10

Figure 16 presents the data on the 50 ohm resonators and shows the relative quality between the different conductors. Several important points are illuminated by Figure 16 : (1) PdAg and PtAu, which are very popular for standard low frequency hybrids would not be acceptable for most microwave applications because of their low Q, (2) Q for the fritless PtAg was 30% better than the fritted PtAg and (3) Copper thick film shows promise as a viable material because of its high Q coupled with its excellent solder leaching resistance.

2.3.2 Adhesion of Thick Film Conductors

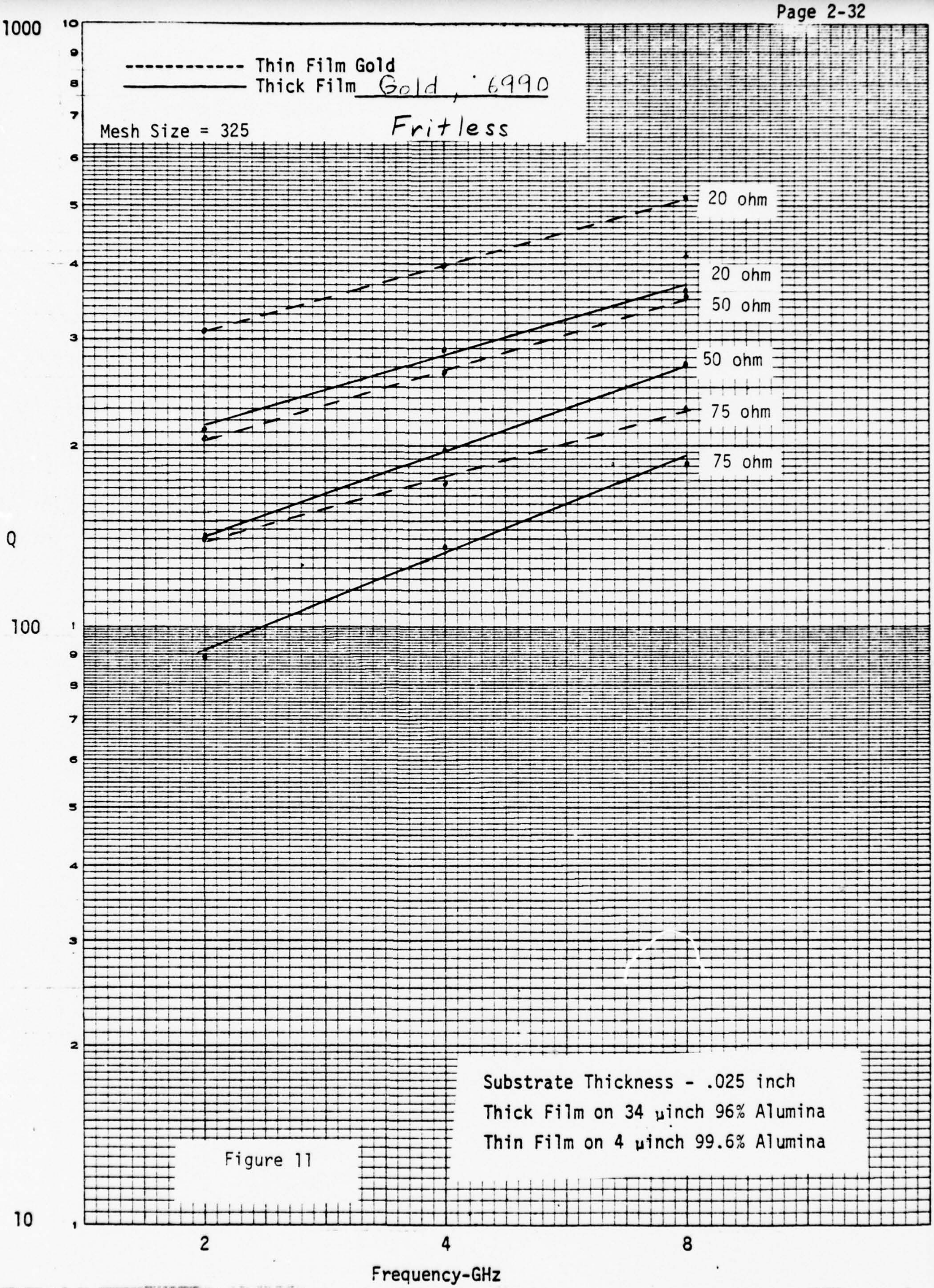
The adhesion of four thick film conductors (see page 2-38) on substrates of various purities and surface roughness was determined. These materials were:

1. MRC (Material Research Corporation)
   96% Al_2O_3 6-8 μinch finish
2. MRC 99.5% Al_2O_3 4 μinch finish
3. AlSi MAG 614 96% Al_2O_3 25-34 μinch finish

The test method is as follows:

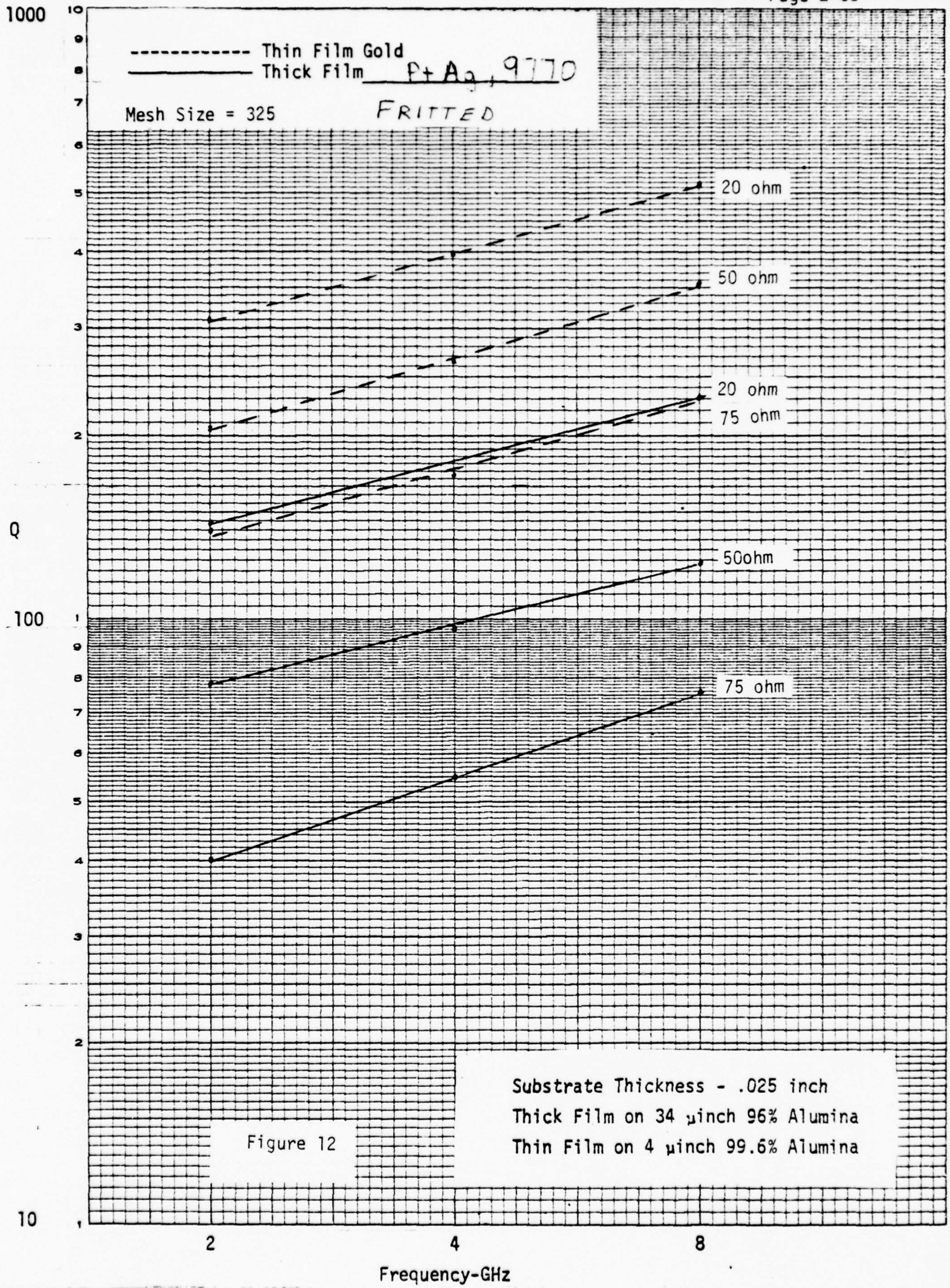
1. Using Kester 1544 flux, solder dip the substrate into 62 Sn/36 Pd/ 2Ag solder.
2. Attach leads to each 80 mil square pad.
3. Pull one-half of the leads on each substrate. Record data.
4. Age substrates in a 150°C environment for 48 hours. Pull the remaining leads and record the data.

Table 5 is a summary of the adhesion test. The two gold materials were not evaluated because of their poor leach resistance. The PtAg 1130 was fired at the wrong temperature. Consequently, the pads almost fell off.



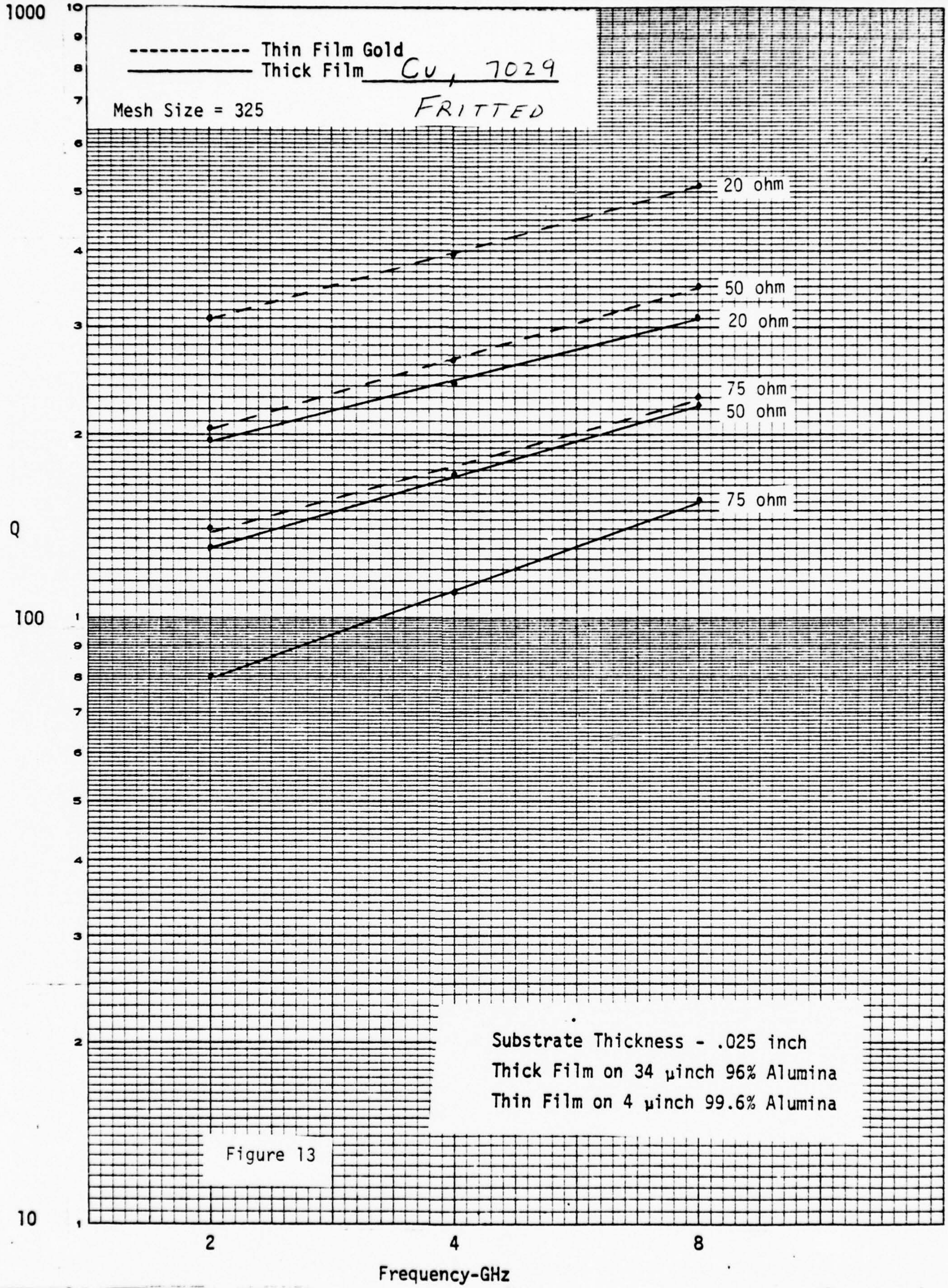
Thin Film Gold
Thick Film Gold, 6990
Fritless
Mesh Size = 325
20 ohm
20 ohm
50 ohm
50 ohm
75 ohm
75 ohm
Q
1000
100
10
2
4
8
Frequency-GHz
Substrate Thickness - .025 inch
Thick Film on 34 µinch 96% Alumina
Thin Film on 4 µinch 99.6% Alumina

Figure 11



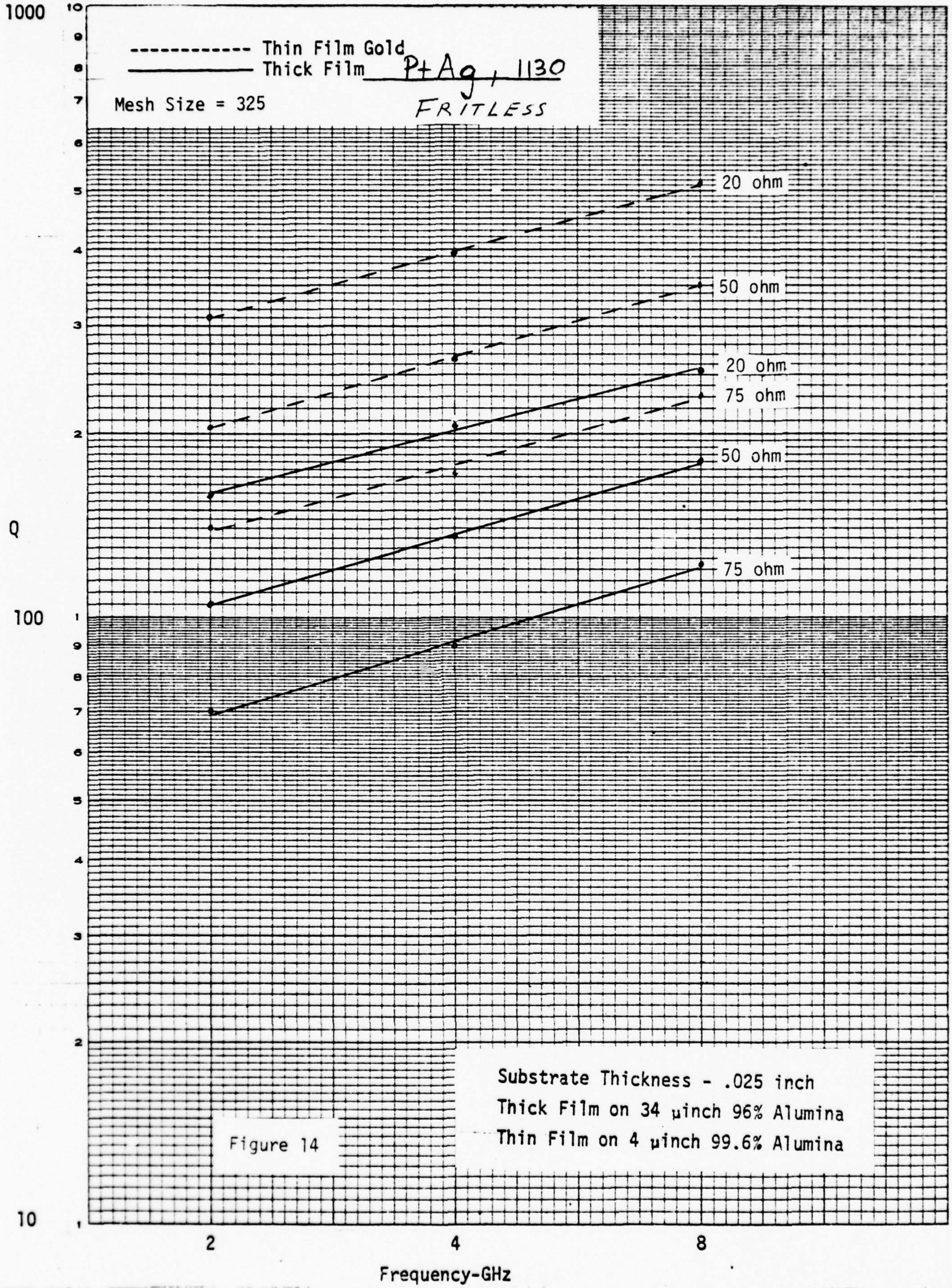
Thin Film Gold
Thick Film Pt Ag, 9770
Mesh Size = 325
FRITTED
1000
100
10
Q
20 ohm
50 ohm
20 ohm
75 ohm
50ohm
75 ohm
2
4
8
Frequency-GHz
Substrate Thickness - .025 inch
Thick Film on 34 µinch 96% Alumina
Thin Film on 4 µinch 99.6% Alumina

Figure 12



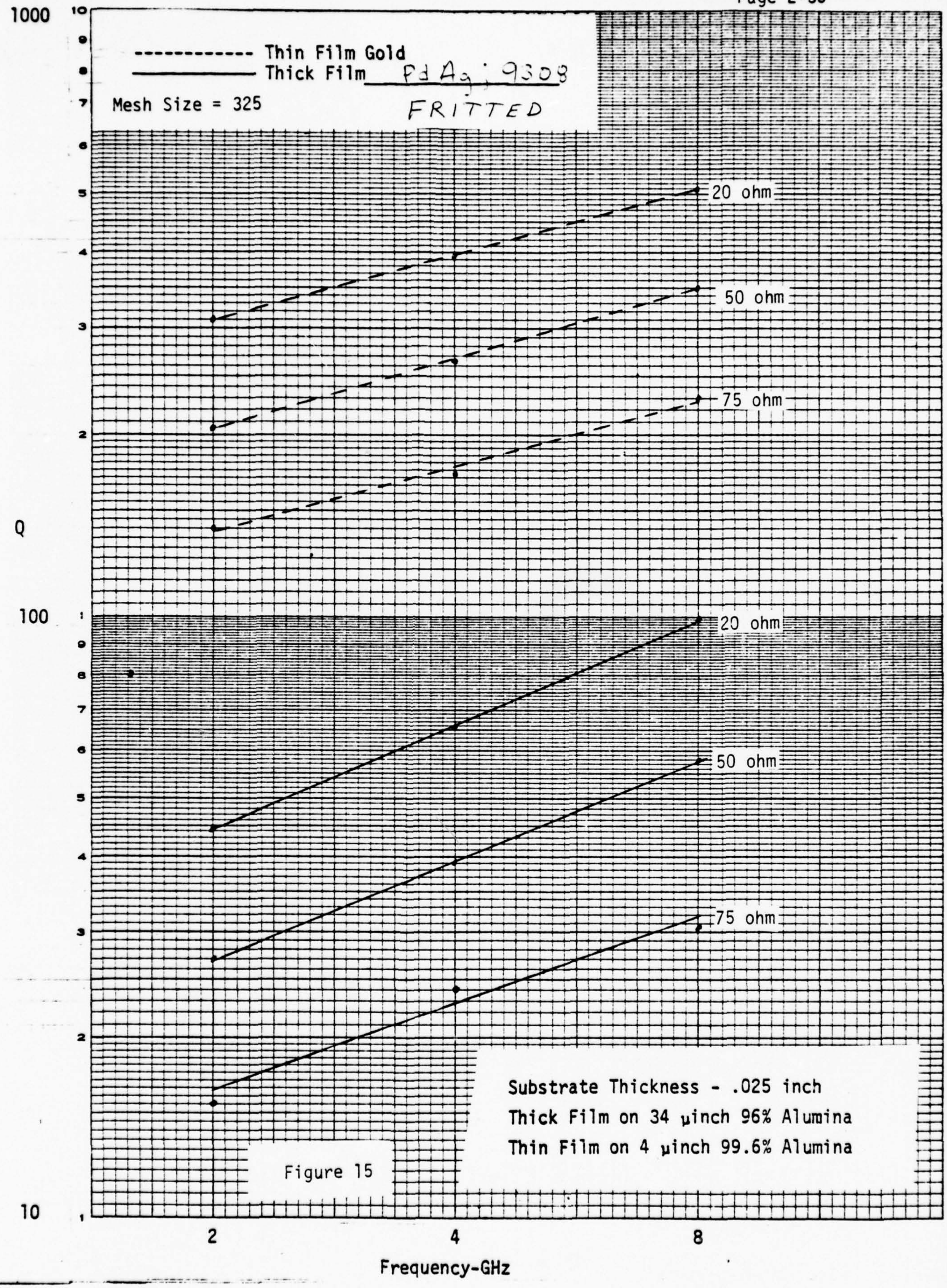
Thin Film Gold
Thick Film Cu, 7029
FRITTED
Mesh Size = 325
20 ohm
50 ohm
20 ohm
75 ohm
50 ohm
75 ohm
Substrate Thickness - .025 inch
Thick Film on 34 μinch 96% Alumina
Thin Film on 4 μinch 99.6% Alumina
1000
100
10
Q
2
4
8
Frequency-GHz

Figure 13



Thin Film Gold
Thick Film Pt Ag, 1130 FRITLESS
Mesh Size = 325
20 ohm
50 ohm
20 ohm
75 ohm
50 ohm
75 ohm
Q
1000
100
10
2
4
8
Frequency-GHz
Substrate Thickness - .025 inch
Thick Film on 34 μinch 96% Alumina
Thin Film on 4 μinch 99.6% Alumina

Figure 14



Thin Film Gold
Thick Film Pd Ag; 9308
FRITTED
Mesh Size = 325
1000
100
10
Q
20 ohm
50 ohm
75 ohm
20 ohm
50 ohm
75 ohm
2
4
8
Frequency-GHz
Substrate Thickness - .025 inch
Thick Film on 34 μinch 96% Alumina
Thin Film on 4 μinch 99.6% Alumina

Figure 15

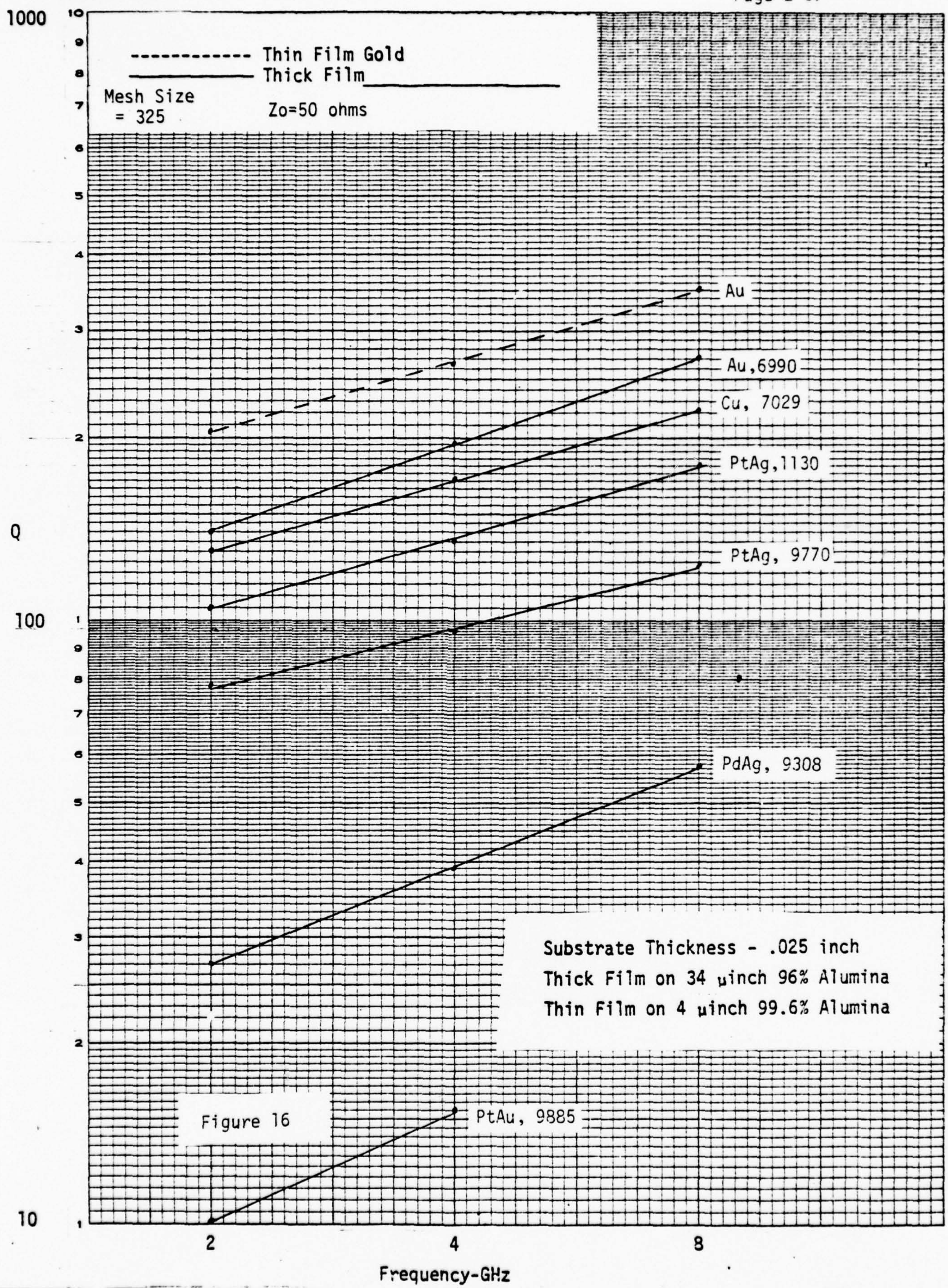

1000
100
10
Q
Thin Film Gold
Thick Film
Mesh Size = 325
Zo=50 ohms
Au
Au,6990
Cu, 7029
PtAg,1130
PtAg, 9770
PdAg, 9308
PtAu, 9885
Substrate Thickness - .025 inch
Thick Film on 34 µinch 96% Alumina
Thin Film on 4 µinch 99.6% Alumina
2
4
8
Frequency-GHz

Figure 16

TABLE 5

ADHESION CHARACTERISTICS OF THICK FILM

Material		96% Al_2O_3 34 μinch		96% Al_2O_3 6-8 μinch		99.5% Al_2O_3 4 μinch	
		t_o (lbs)	t_{48} (lbs)	t_o (lbs)	t_{48} (lbs)	t_o (lbs)	t_{48} (lbs)
Cu	$\overline{X}$	15.97	.94	11.19	5.53	9.61	.95
	σ	2.15	.69	1.44	2.27	3.77	.46
PtAg 9770	$\overline{X}$	6.88	.73	12.66	.28	5.56	.3
	σ	2.28	.3	2.45	.078	2.49	.11
PdAg 9308	$\overline{X}$	7.12	4.54	6.42	3.86	1.69	1.37
	σ	2.26	1.13	1.12	1.14	.37	.42
PtAu 9885	$\overline{X}$	5.93	5.84	7.04	5.68	6.27	2.65
	σ	1.35	1.66	1.55	1.75	1.35	.79

$\overline{X}$ = AVERAGE

σ = STANDARD DEVIATION

2.3.3 Resistivity of Thick Film Conductors

The resistivity of the seven previously mentioned thick film conductors was determined by measuring the resistance of a long meandering line and multiplying by width/length. The results are shown in Table 6.

TABLE 6

Material	ρ, (mΩ/□)
9791 Au	2.81
7029 Cu	2.89
6990 Au	3.44
9770 PtAg	3.45
1130 PtAg	3.99
9308 PdAg	31.22
9885 PtAu	115.78

2.4 PROCESS, EQUIPMENT AND TOOLING

2.4.1 Radiosonde Modulator/Transmitter

Modulator Hybrid Assembly - Referring to Figure 17, the assembly sequence for the modulator hybrid is as follows:

1. Screen conductor material, Dupont 9308 PdAg, using the Weltek, Model 44, Precision Screen Printer.
2. Dry the substrate in the Presco belt furnace for 20 minutes. See Figure 18 for the temperature profile.
3. Fire the substrate in the Linberg belt furnace. See Figure 19 for the temperature profile. Maximum temperature is 860°C.

4. Repeat Steps 1 and 2 three times for the resistor pastes ($10\Omega/\square$, $1k\Omega/\square$ and $10k/\square$).
5. Fire resistors in the Linberg belt furnace.
6. Trim resistors to the desired values on the Terradyne computer-controlled laser system, Model W311.
7. Screen on 95Pb/5Sn solder paste using the Weltek printer.
8. Laser score and break substrates to final size on the manual Yag laser system.
9. Mount the flip chips, LID zener, crossovers and capacitors.
10. Reflow solder, using the BTU Engineering Corporation belt furnace. See Figure 20 for temperature profile.
11. Autotest hybrid.
12. Apply conformal coating.

Step 1 calls for the screening of PdAg 9308 conductor material. It was stated in Section 2.1.3 that this material is not suitable for most microwave applications due to high circuit losses. However, for standard low frequency hybrid applications such as the Radiosonde Modulator, PdAg is one of the more popular materials because of its high solder leach resistance, excellent resistor system compatability and low cost.

Step 7 calls for screening solder onto the substrate. This procedure is used because solder is needed for capacitor, crossover and zener attachment and, very importantly, because solder is needed on the flip chip pads. The flip chips have solder bumps of 95 Pb/5Sn solder on the face of the active side; however, the amount of solder on these bumps is not enough to ensure that what the industry refers to as a "controlled collapse" takes place. During the engineering phase, we have been solder dipping the substrate instead of solder screening. Not only is

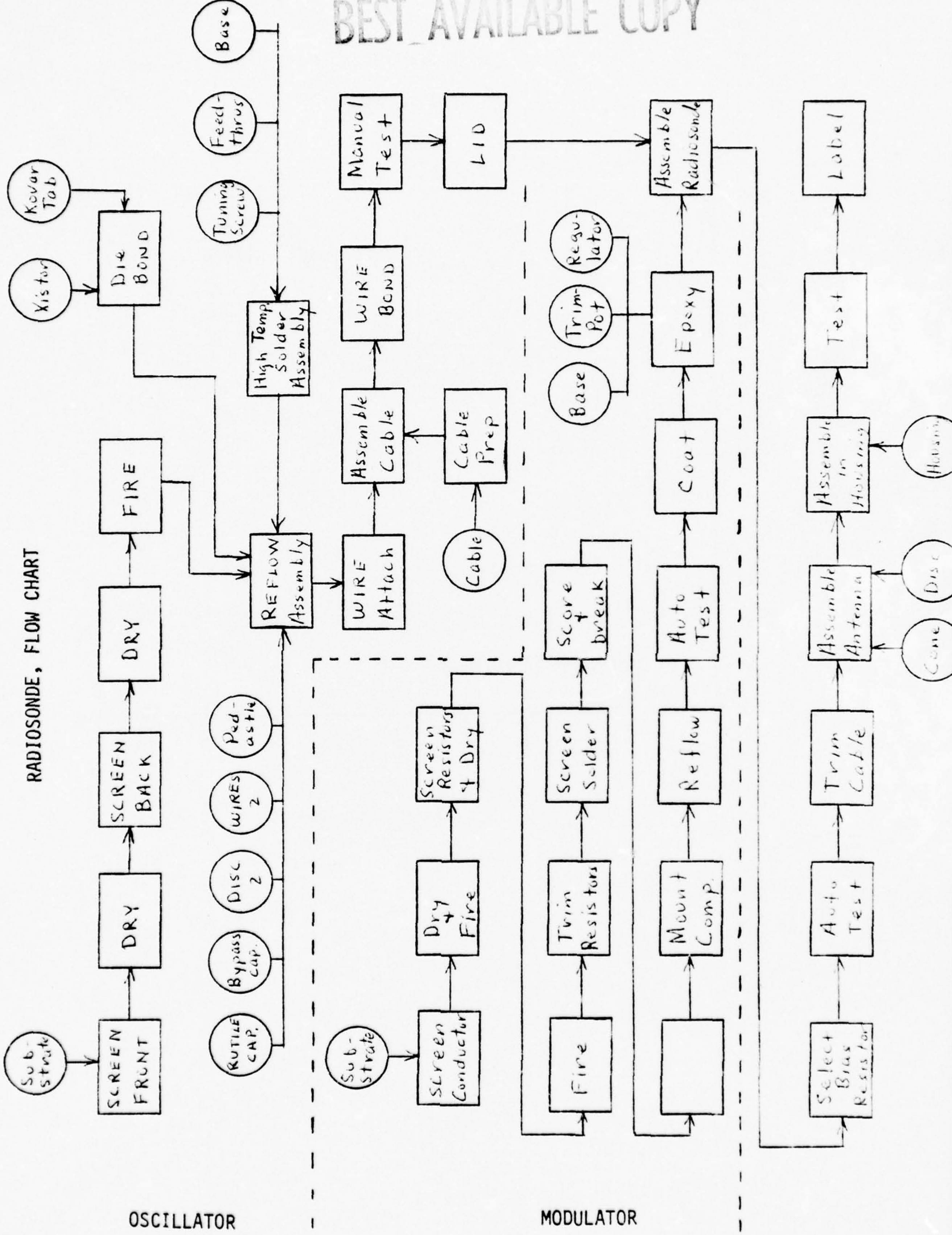

RADIOSONDE, FLOW CHART
Sub-strate
SCREEN FRONT
DRY
SCREEN BACK
DRY
FIRE
Xistor
Kovar Tab
DIE BOND
RUTILE CAP.
Bypass Cap.
DISC 2
WIRES 2
Ped-astle
REFLOW Assembly
High Temp Solder Assembly
Tuning Screw
Feed-thrus
Base
WIRE Attach
Assemble Cable
WIRE BOND
Manual Test
Cable
Cable Prep
LID
Sub-strate
Screen Conductor
Dry + Fire
Screen Resistors + Dry
Fire
Trim Resistors
Screen Solder
Score + break
Mount Comp.
Reflow
Auto Test
Coat
Base
Trim Pot
Regu-lator
Epoxy
Assemble Radiosonde
Select Bias Resistor
Auto Test
Trim Cable
Assemble Antenna
Cone
Disc
Assemble in Housing
Housing
Test
Label
OSCILLATOR
MODULATOR

Figure 17

DRYER BELT FURNACE

TEMPERATURE PROFILE

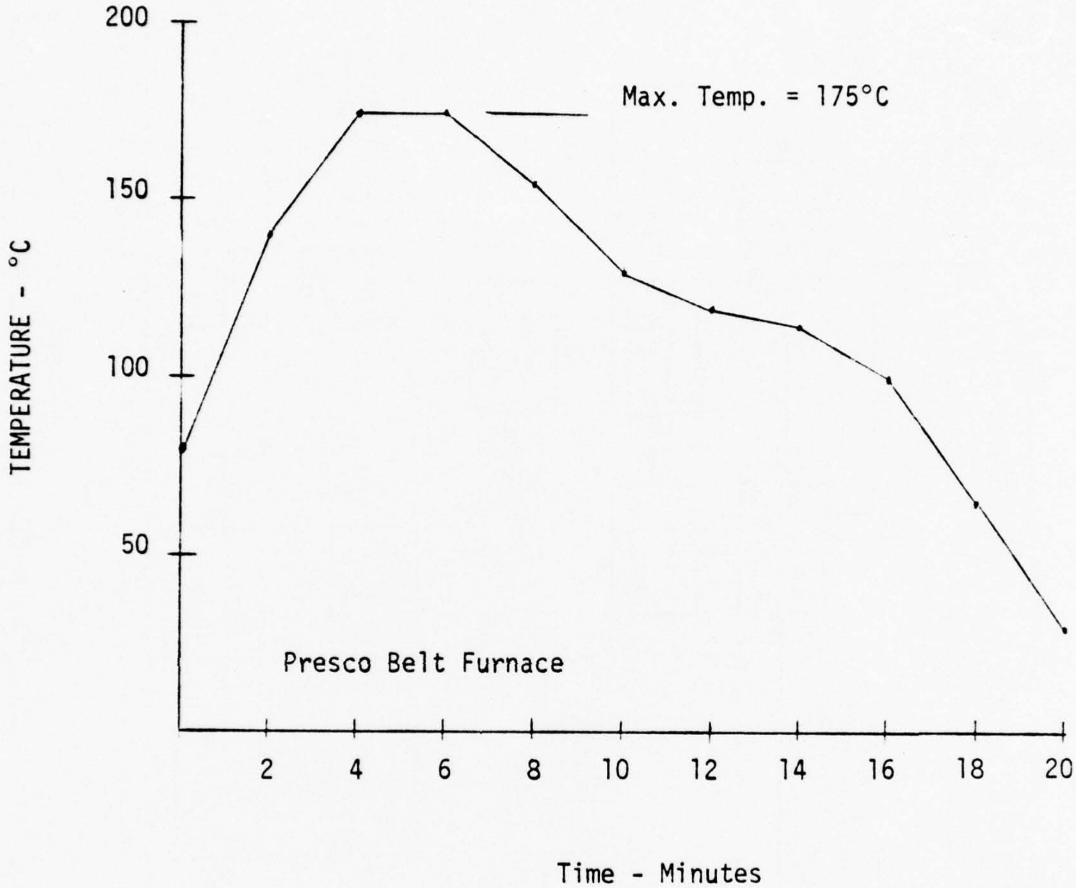


Figure 18

THICK FILM

FIRING TEMPERATURE PROFILE

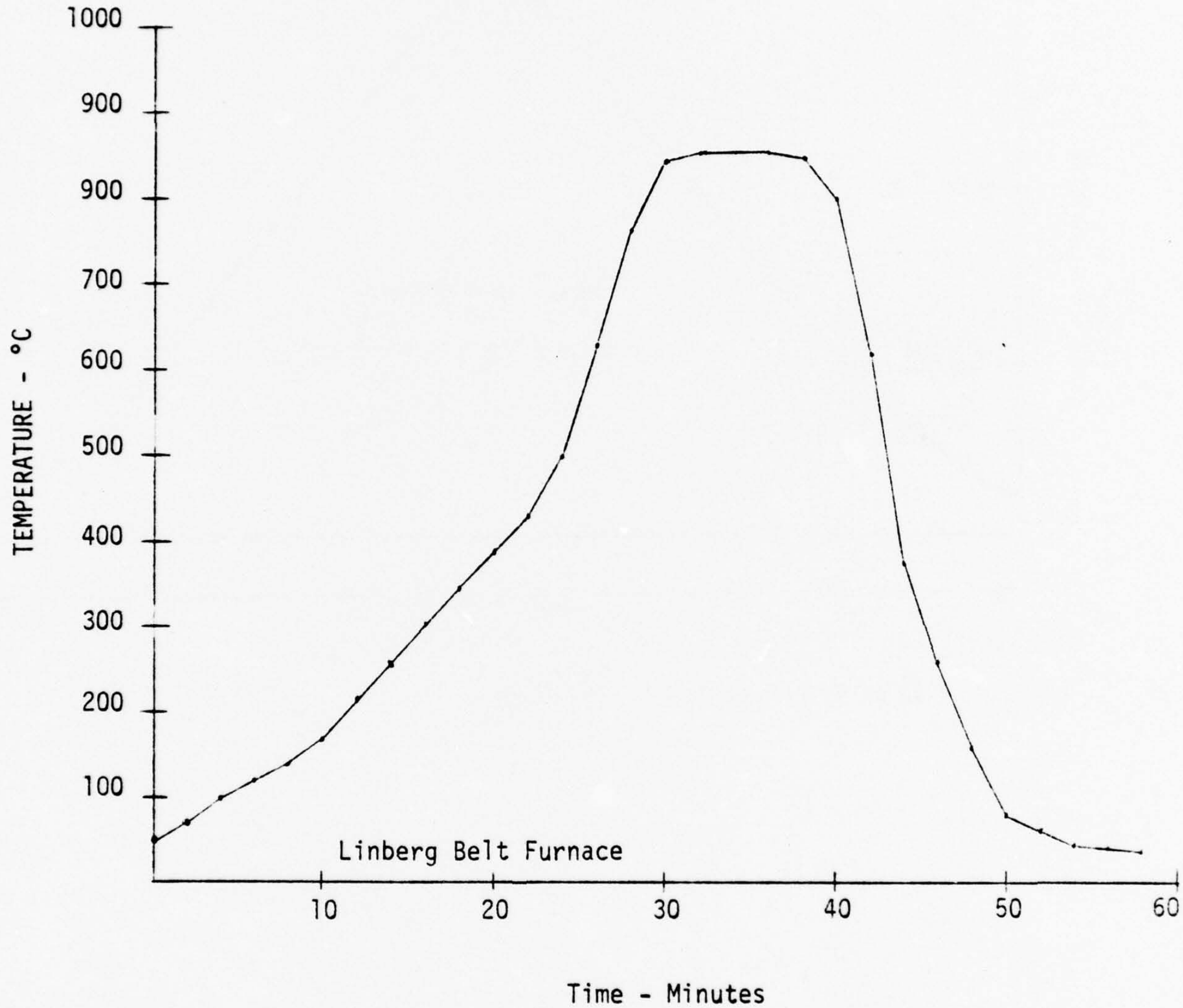


Figure 19

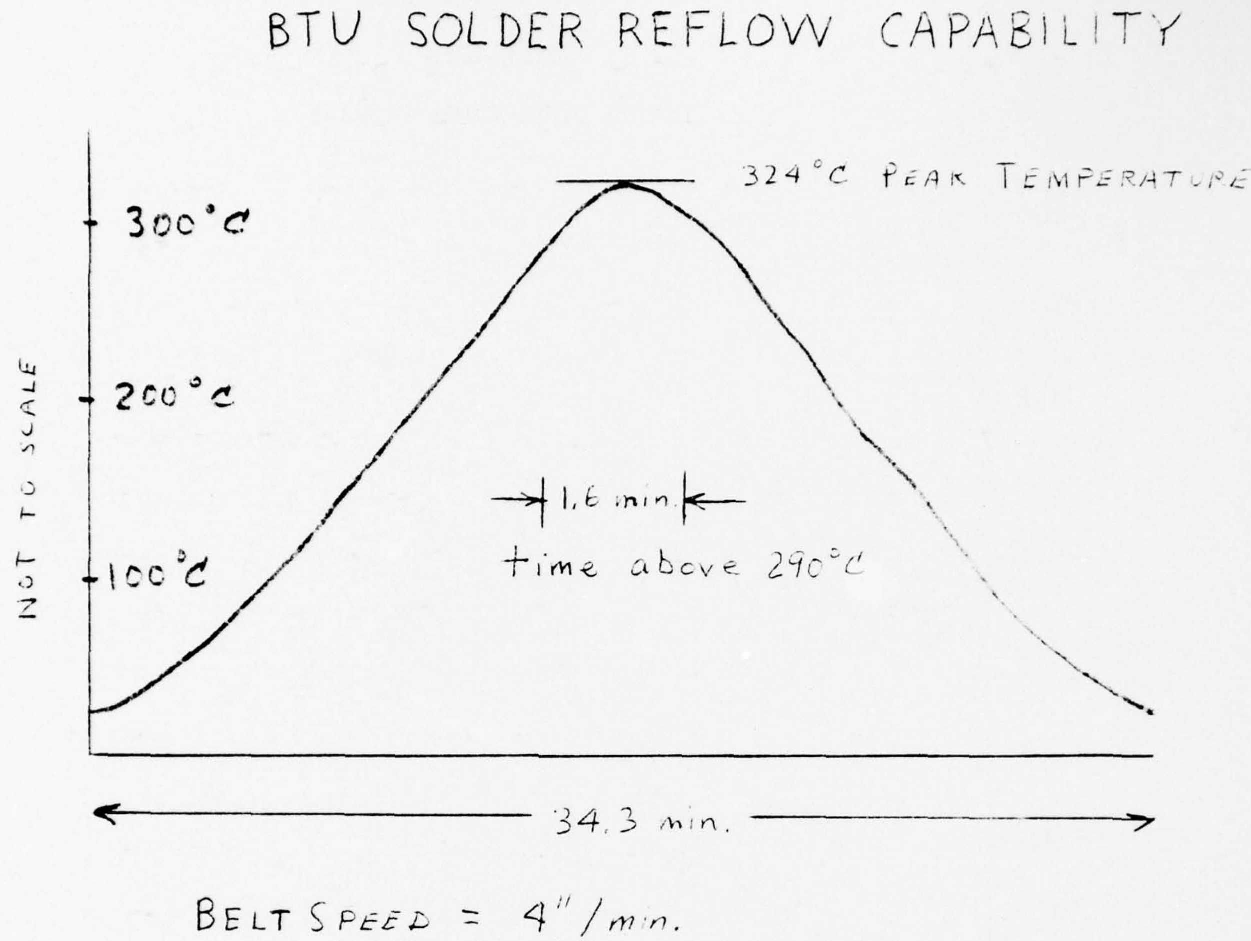

BTU SOLDER REFLOW CAPABILITY
324°C PEAK TEMPERATURE
300°C
200°C
100°C
NOT TO SCALE
1.6 min.
time above 290°C
34.3 min.
BELT SPEED = 4"/min.

Figure 20

solder dipping a tremendous thermal shock which could crack a substrate, but it does not guarantee that solder will stick to the 8 mil square flip chip pads. Two or three solder dips are necessary at times to get solder to stick to all the pads. Solder dipping also requires that the substrate be coated with flux before mounting the components.

Oscillator Assembly - The substrates used in the oscillator were purchased prepunched from the 3M Company. They were then screened with PtAg paste and fired, using the same equipment and processes as the modulator hybrid. All the oscillators built for the second engineering samples were assembled by using a hot plate reflow technique. The assembly steps were as follows:

1. The 2N5109 transistor chip is die-bonded to a 40 mil square Kovar tab.
2. The feedthru pins, cable retainer and tuning screw holder are attached to the oscillator base plate, using a high temperature, gold tin solder paste (Alpha Metals #67927, melting temperature 287°C). A special holding fixture was fabricated to allow the parts to be laid flat, upside down on the hotplate while the solder was reflowing.
3. The remaining parts, the rf disc, the tuning disc, bypass capacitors rutile capacitor, pedestal and die-bonded transistor are attached, using a 62Sn/36Pb/2Ag Dupont Formon solder paste #8956 (melting temperature 187°C). Again, a holding fixture was created to align the substrate and keep the parts from floating around during the reflow process. This step was also accomplished on a hot plate but could potentially be done in a reflow belt furnace.

4. The remaining steps are to solder two wires from the substrate to the bypass capacitors and the feedthru terminals and to wirebond the transistor, using the K&S 422-1 bonder. This bonder has just recently been modified to allow the radiosonde oscillator and the FM Source to be wirebonded during the final assembly stages without having to remove the coax cable or the tuning screw. This modification will also simplify transistor and diode repair.

Voids Under Substrate - A number of assembled oscillators were X-rayed to determine the bonding effectiveness of the reflow process. Quite a few voids were found under the substrates, but they did not affect the circuit operation. What problems the voids may cause and how to eliminate them is being investigated.

2.4.2 FM Source

Figure 21 is the assembly flow chart for the FM Source. It calls out many of the same operations as in the assembly of the radiosonde and uses the same equipment. The chip capacitors and grounding straps are mounted, using a gold/tin solder paste. All other soldering operations use a 63Sn/37Pb solder. In the event that a unit requires a diode or transistor repair, the K&S 422-1 bonder has been modified to accept the FM Source without having to disassemble the coax cable. After passing the precap acceptance test, units will be lidded, most likely using a modified parallel seam sealer from the Solid State Equipment Corporation.

FM SOURCE, FLOW CHART

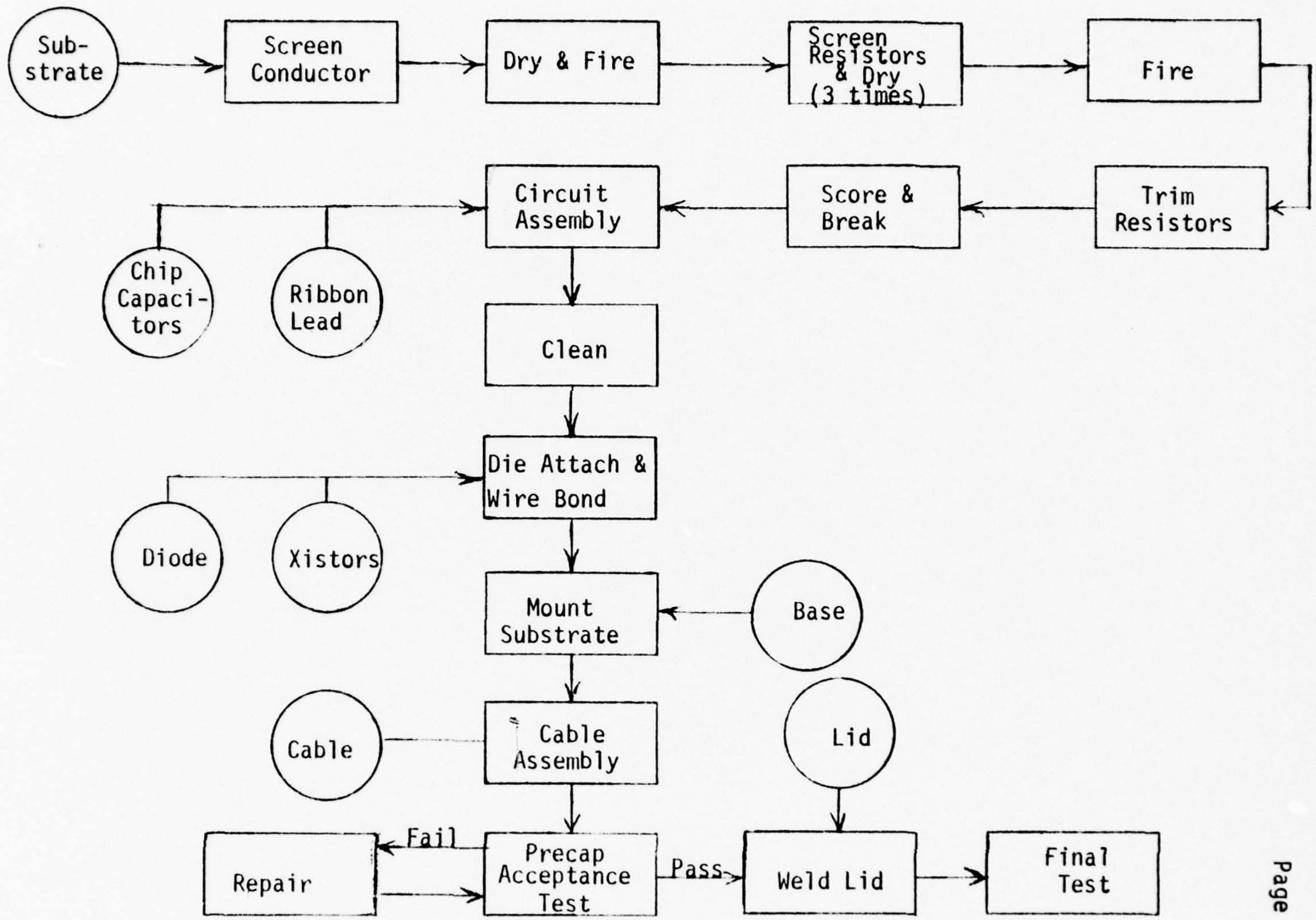


Figure 21

SECTION 3

CONCLUSIONS

3.1 Radiosonde Modulator/Transmitter

Excellent progress has been made this past quarter in clearing up the electrical problems associated with the first engineering samples, particularly the tuning range and the modulator transfer characteristic. However, further effort is required on the frequency stability problem. Progress has also been made in determining the assembly techniques and processes required for high volume production. Particular emphasis has been placed on reflow solder techniques which eliminate many hand labor operations.

3.2 FM Source

Not as much progress has been made on the FM Source as originally anticipated. This is in part due to time lost because of incorrect input impedance data and because efforts were concentrated on the radiosonde electrical problems. Progress has been made on lowering the PA input VSWR, and it is fully expected to be under control for the the third engineering samples. Improvements have been made to ease the substrate fabrication and assembly of the FM Source. Efforts are required to ensure that the 30,000g shock level can be sustained,to hermetically seal the unit and to further ease the assembly operation.

SECTION 4

PROGRAM FOR NEXT INTERVAL

4.1 Radiosonde

The Following objectives are planned for the next reporting period:

1. Resolve modulator hybrid substrate cracking problem.
2. Refine oscillator assembly technique.
3. Adjust modulator layout to make it compatible with the computer laser trim system.
4. Write autotest programs for the modulator hybrid and the radiosonde modulator/transmitter.
5. Fabricate and test the third set of engineering samples.

4.2 FM Source

The following objectives are planned for the next reporting period:

1. Fabricate and test the third set of engineering samples.
2. Finalize input match to PA.
3. Adjust circuit layout to make it compatible with the computer laser trim system.
4. Write autotest program.
5. Develop lid welding capability.

4.3 Materials Evaluation

The following objectives are planned for the next reporting period:

1. Evaluate the change in Q for various substrate coatings.
2. Evaluate screened thru hole process.
3. Evaluate wirebond pull strength for thick film conductors.

SECTION 5

5.0 IDENTIFICATION OF PROJECT PERSONNEL

The personnel directly related to the ECOM project are listed in Table 7 along with the number of hours in which they have been involved during this quarter. Resumes of personnel new to the project are included.

Table 7

Identification of Project Personnel

Personnel	Titles	Hours
R. E. Shipley	Project Engineer/Program Manager	27
H. D. Jenkins	Mechanical Engineer/Group Head	6.5
L. G. Ward	Design Engineer (Mech.)	110
C. L. Fox	Senior Technician	483
R. Caddenhead	Senior Process Engineer	35
J. K. McCoy	Design Engineer (Elec.)	513
J. H. Davis	Design Engineer (Elec.)	231

JOHNNY H. DAVIS

POSITION: Design Engineer, RF Products
Hybrid Microelectronics Division

EDUCATION: BSEE, TEXAS A & M UNIVERSITY, 1966

Mr. Davis joined Collins after graduation in 1966 as a Test Equipment Design Engineer, responsible for planning, design, fabrication and construction of various types of production test equipment. This effort required a broad knowledge of all types of products and usually involved the use of state-of-the-art components and design techniques. A thorough knowledge of commercially made test equipment was required.

Following the above, Mr. Davis worked as a Quality Control Engineering Supervisor, responsible for a number of Q. C. engineers who provided line support and customer interface. He was responsible for determining manning requirements, operating budgets, and test equipment requirements for a wide variety of product lines from computers to Microwave equipment.

In 1974, Mr. Davis began work as a Hybrid Microelectronics Applications Engineer, responsible for the design, fabrication, testing and line support for high-reliability hybrids used in equipment such as inertial navigation devices and the NASA Space Shuttle program. He also spent a period of time as a program manager, responsible for customer interface, scheduling and cost tracking.

Mr. Davis is a member of I.E.E.E.

SECTION 6

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SECTION 7

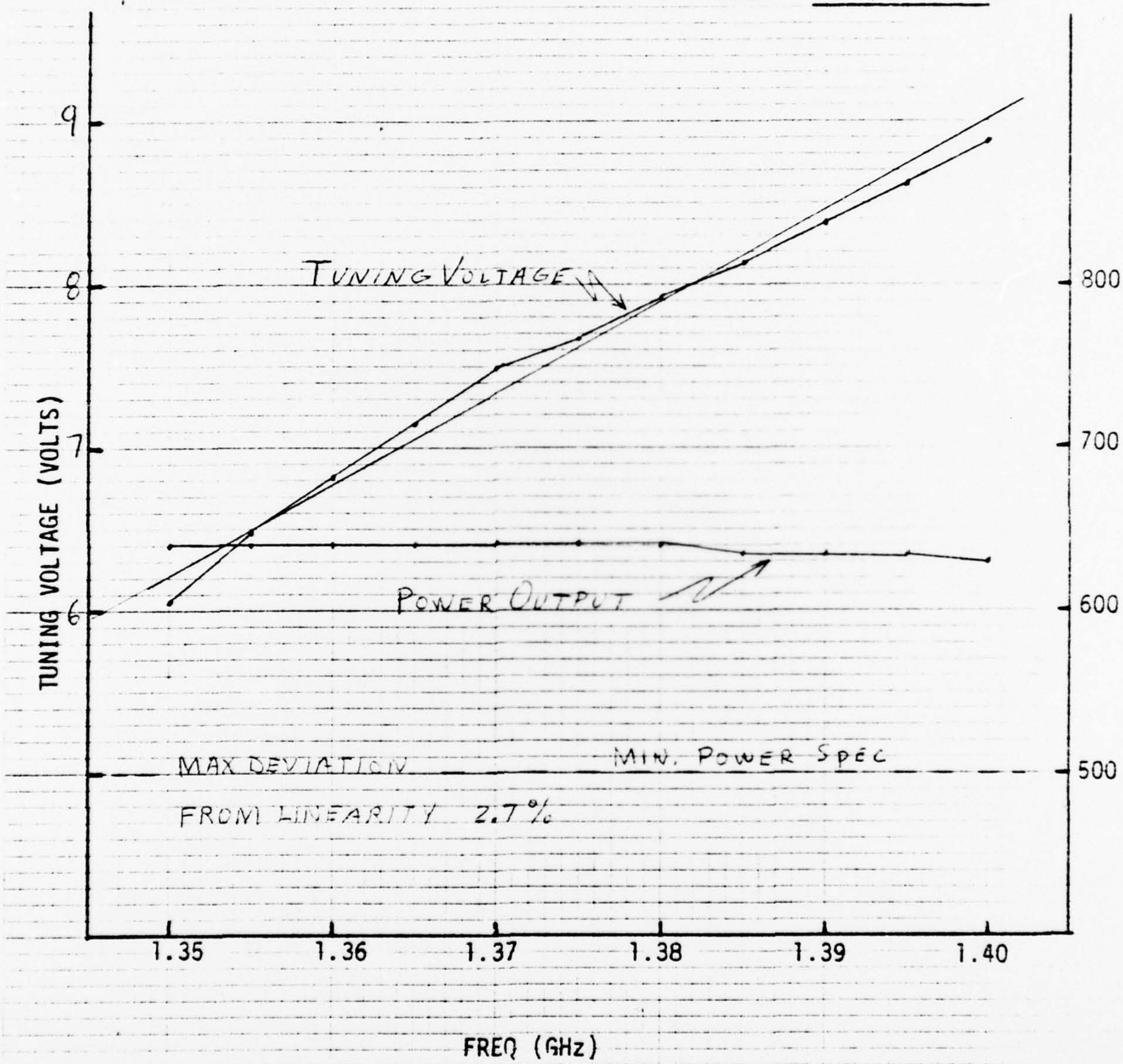
APPENDIX

Pages 7-2 through 7-11 contain graphic data on the FM Sources representing the second set of engineering samples. The number denoted "Max Deviation *from* Linearity" was based on an incorrect definition of first order linearity. Refer to page 2-24 for further clarification.

FM SOURCE

Ser. No. 11

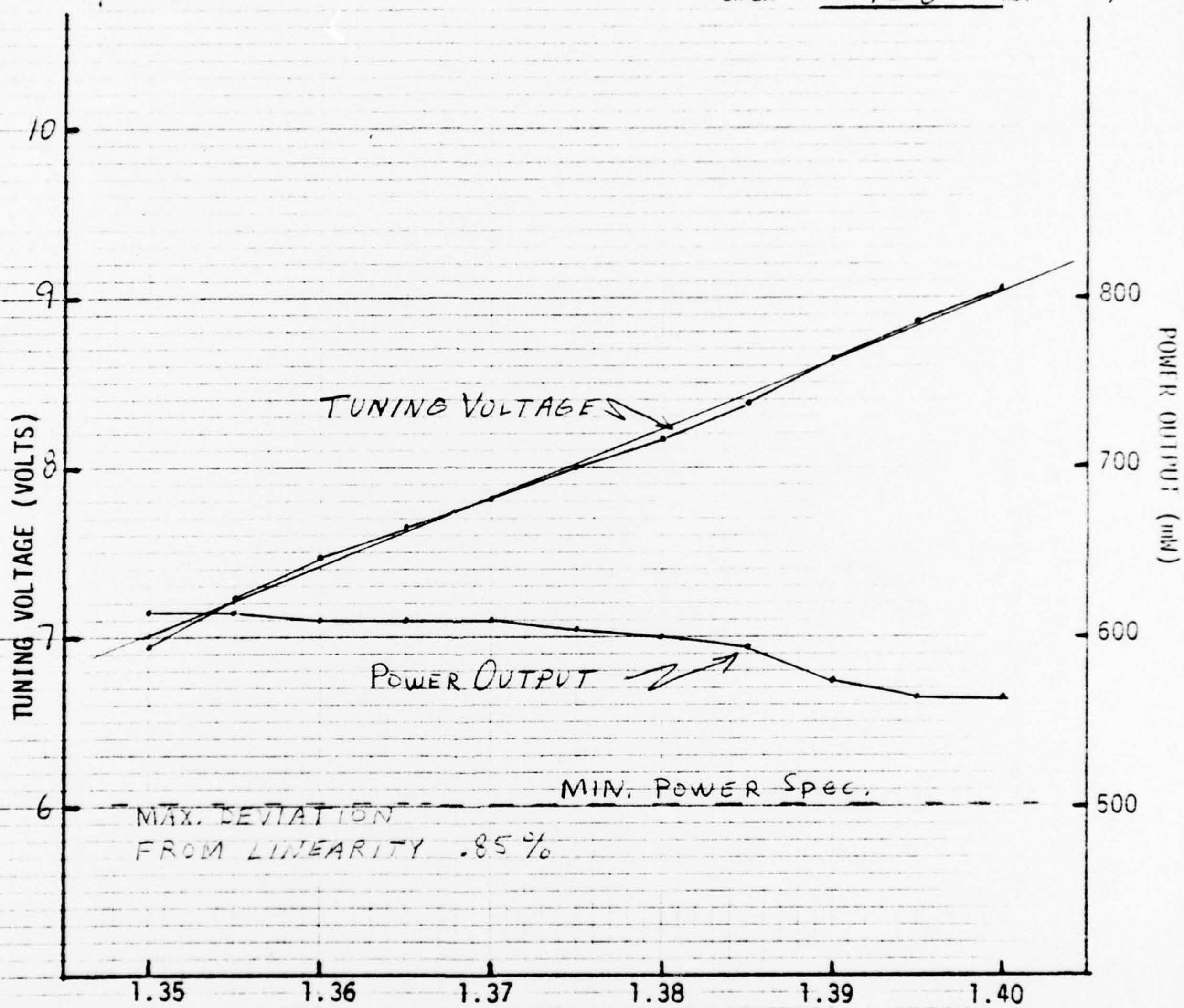
Imax = 154 mA



FM SOURCE

Ser. No. 12

Imax = 158 mA

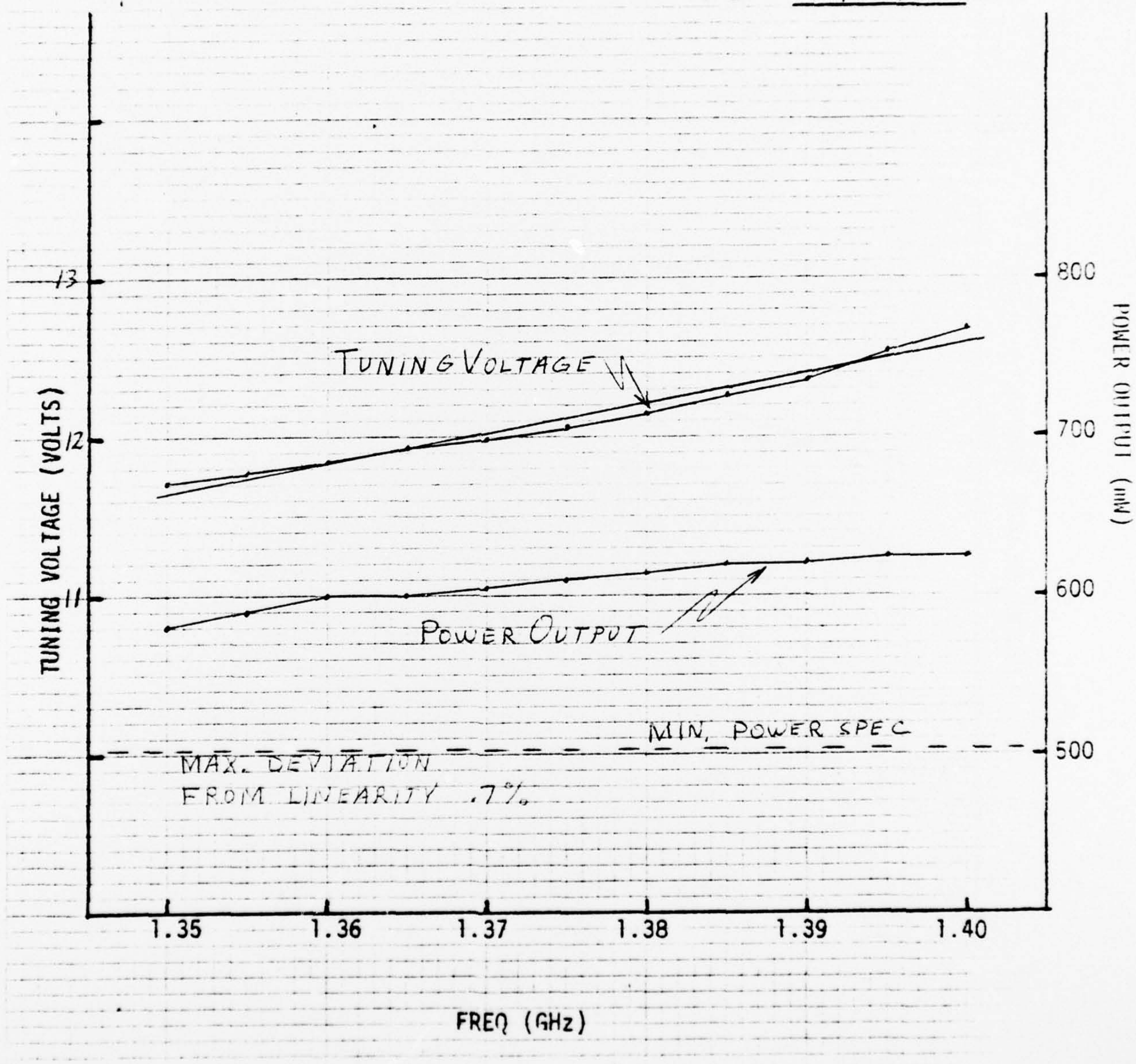


FREQ (GHz)

FM SOURCE

Ser. No. 13

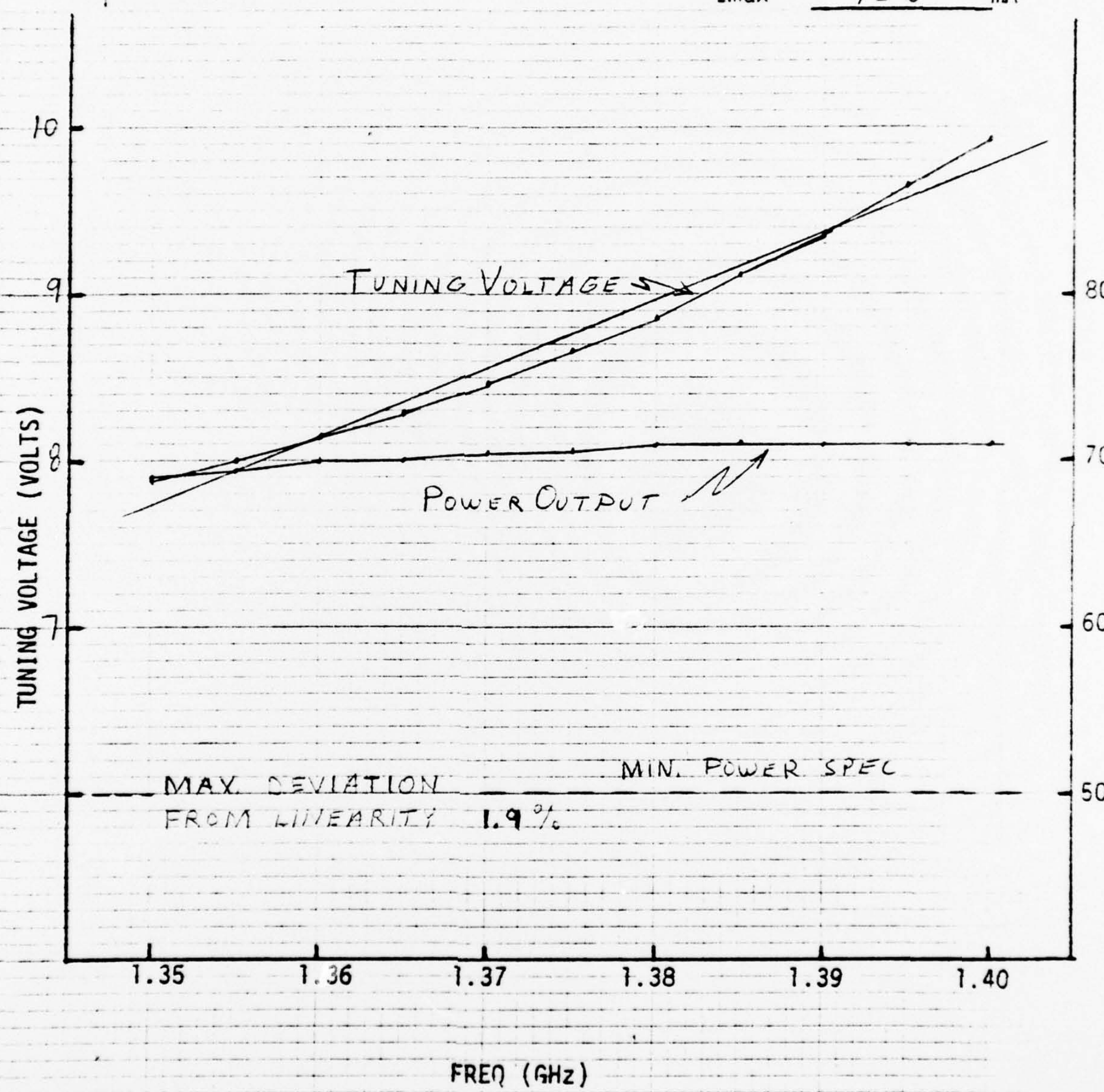
Imax = 154 mA



FM SOURCE

Ser. No. 14

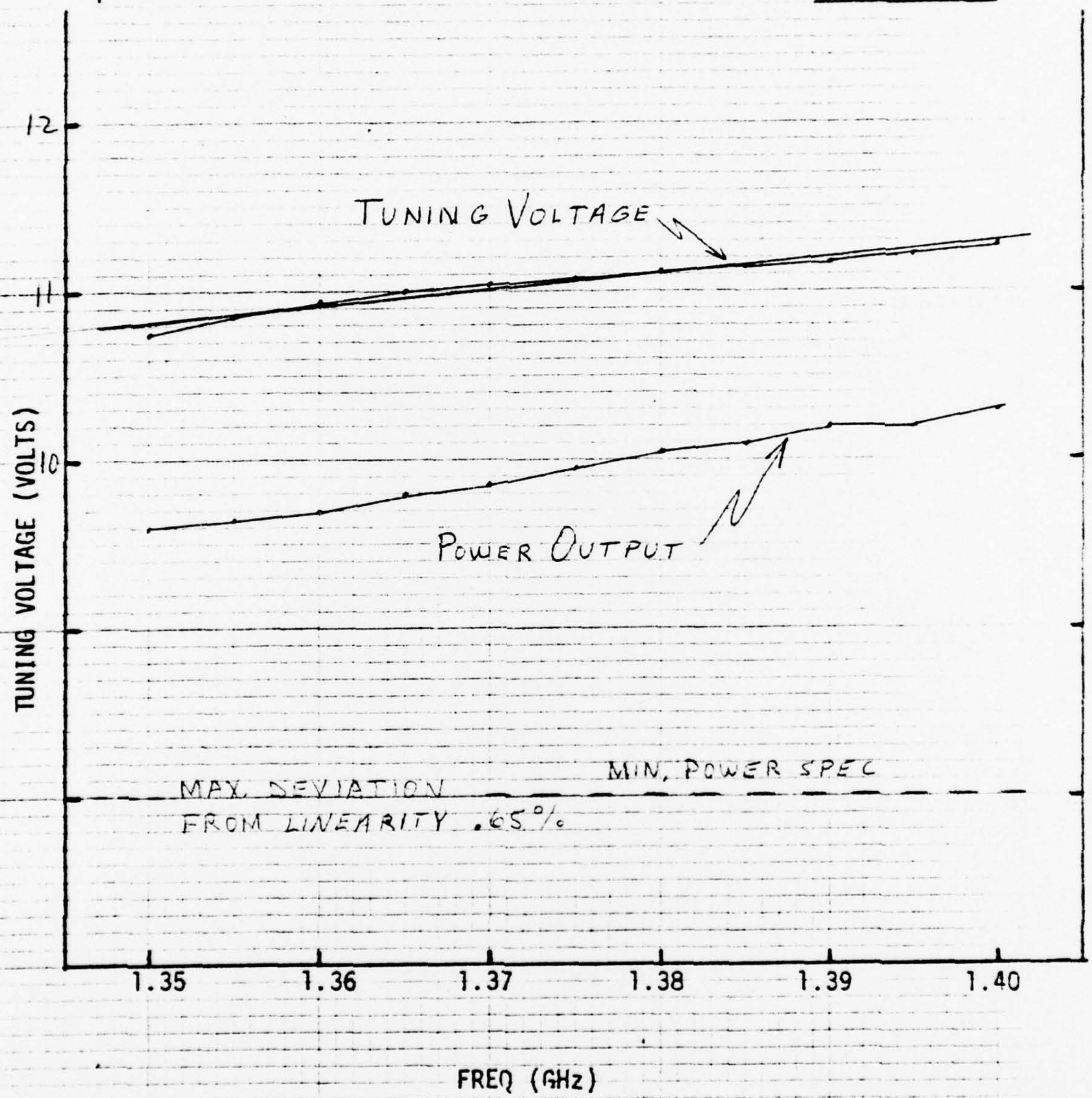
Imax = 156 mA



FM SOURCE

Ser. No. 15

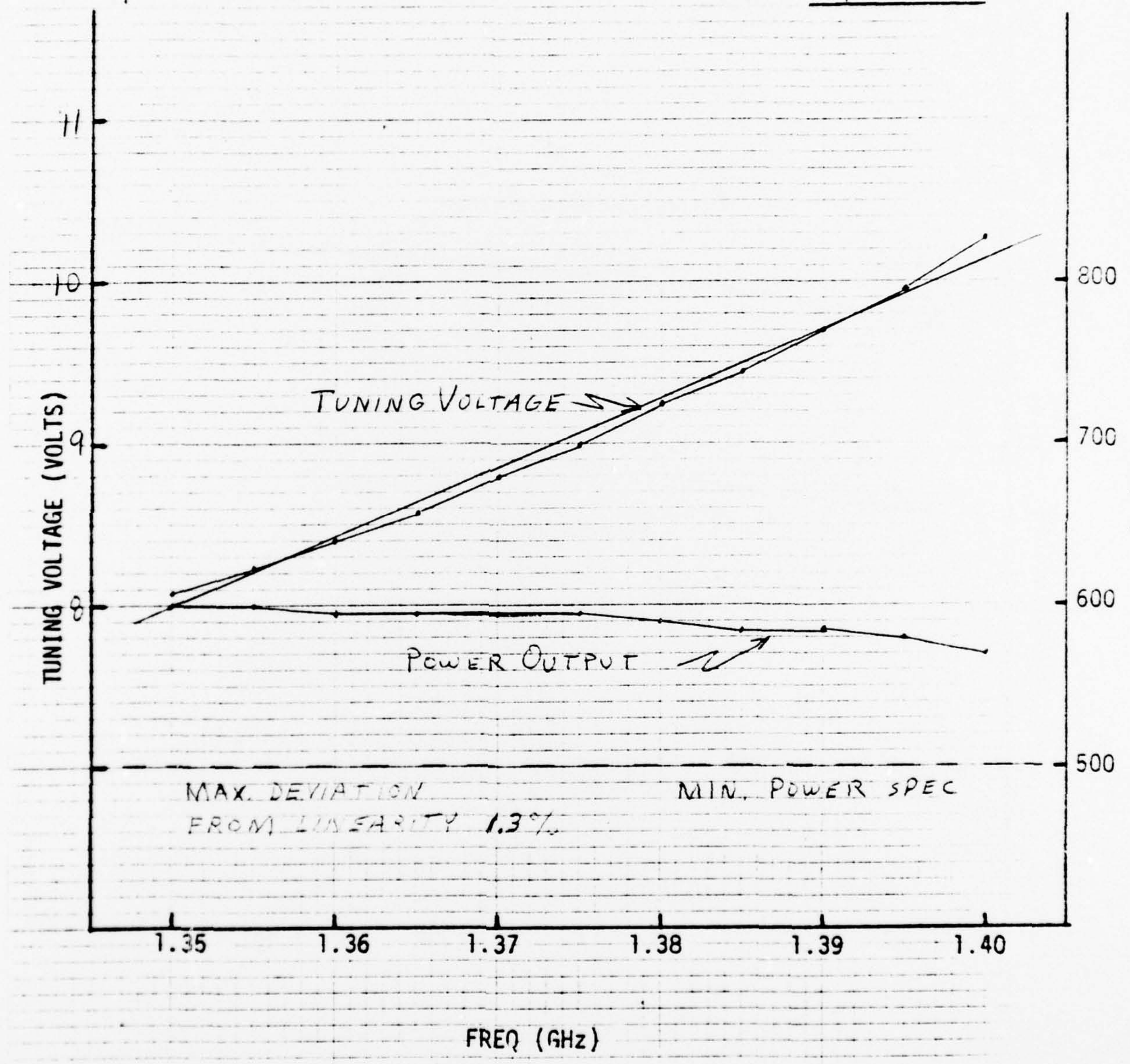
Imax = 167 mA



FM SOURCE

Ser. No. 16

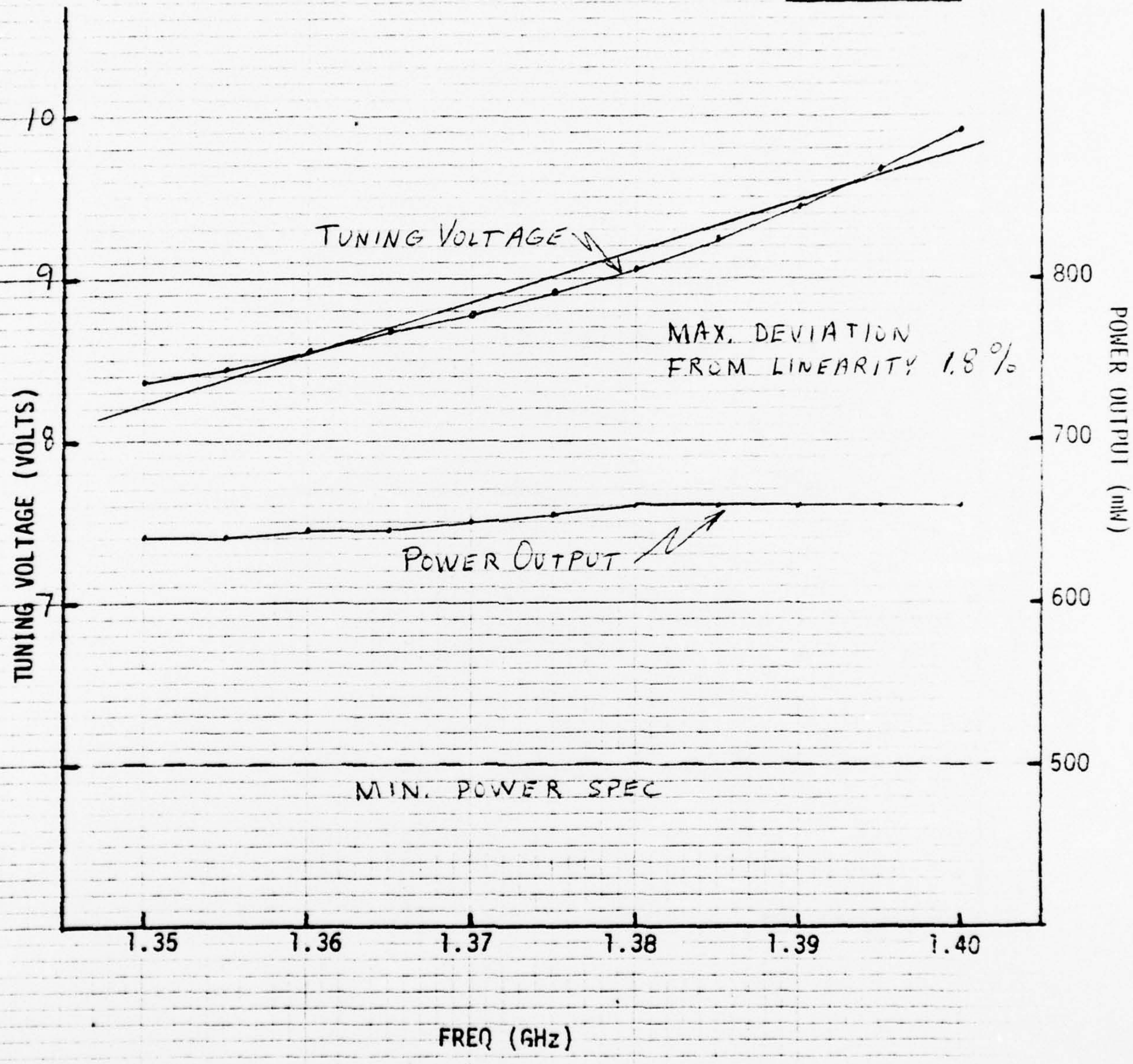
Imax = 154 mA



FM SOURCE

Ser. No. 17

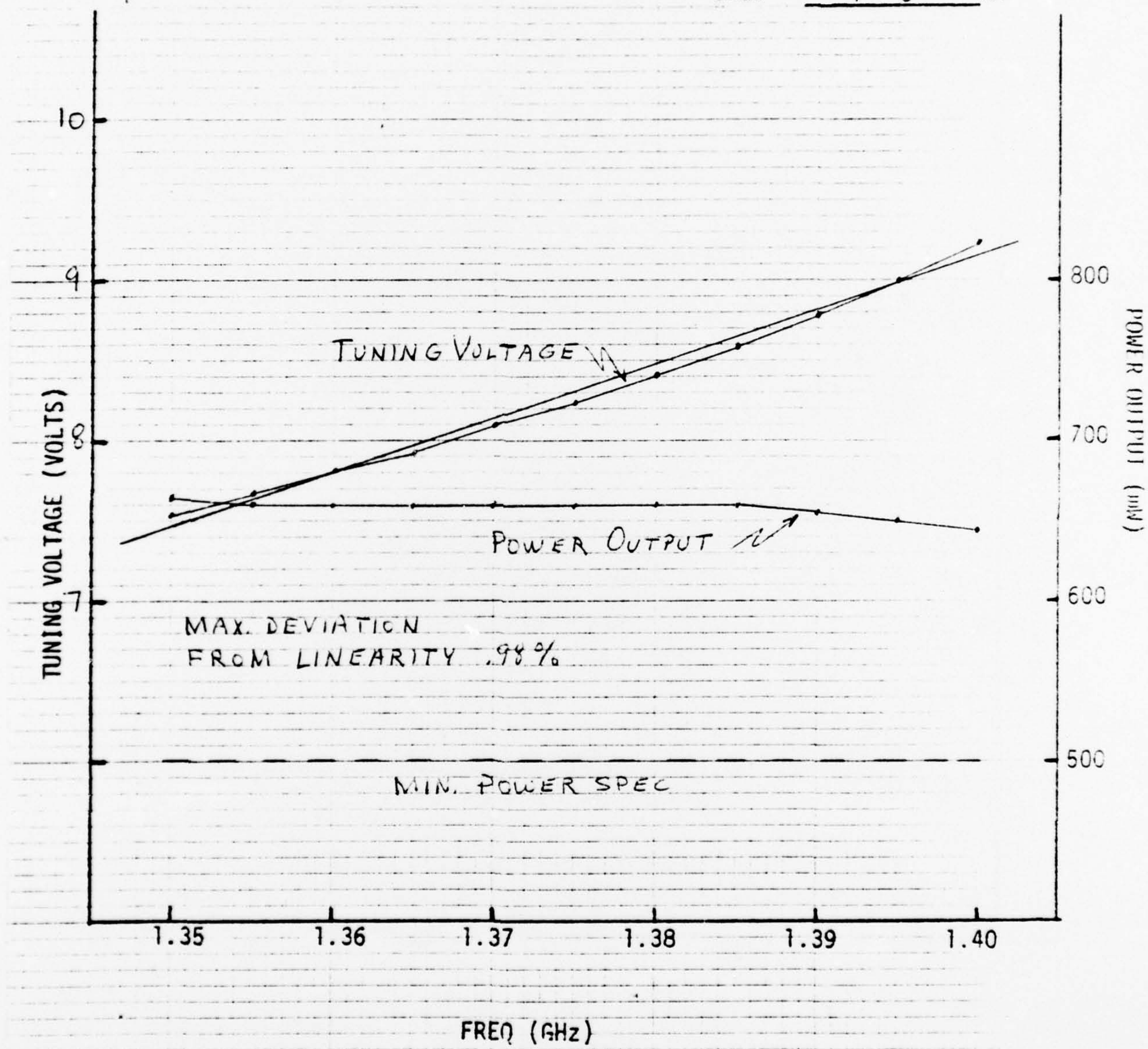
Imax = 154 mA



FM SOURCE

Ser. No. 18

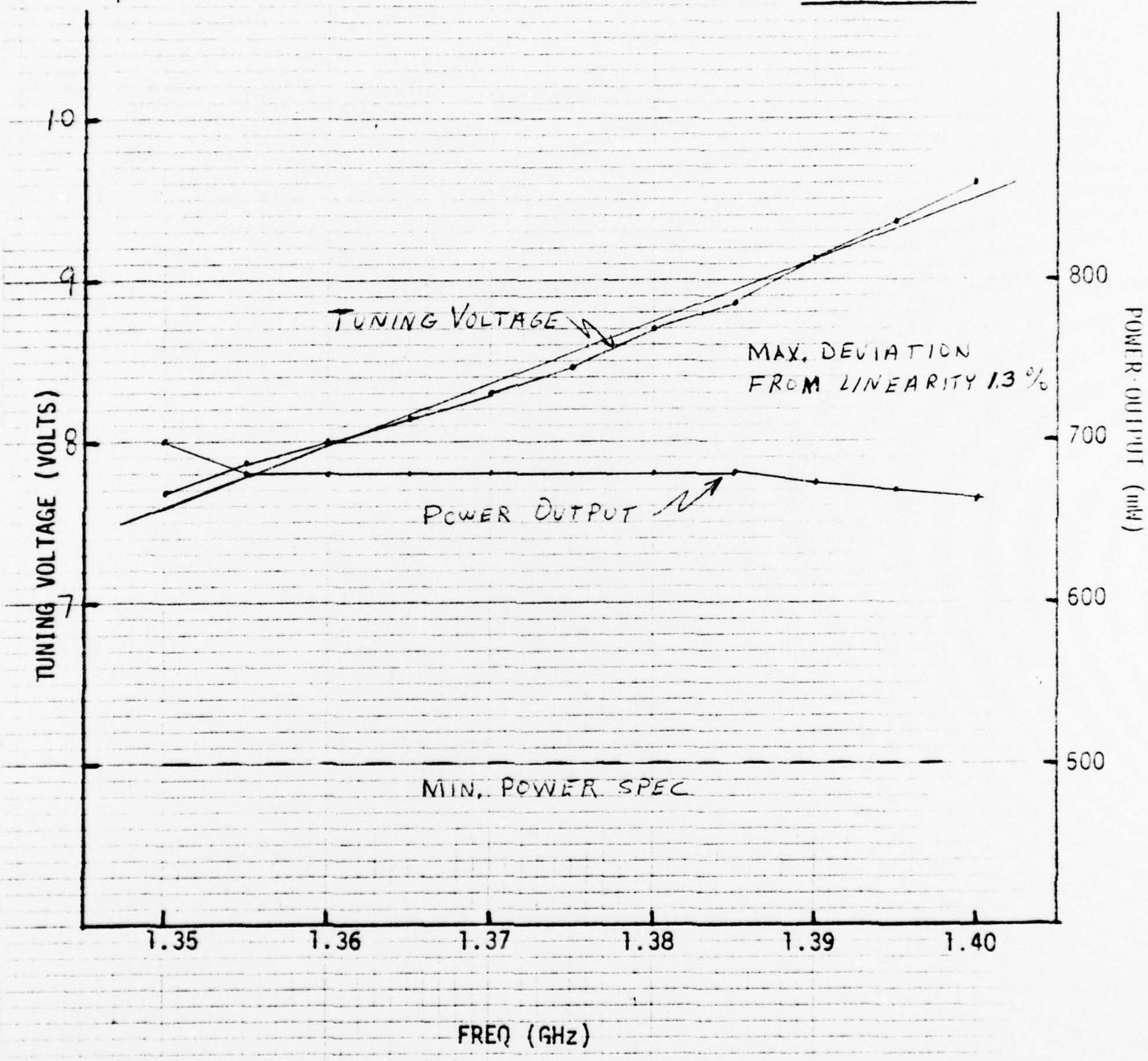
Imax = 148 mA



FM SOURCE

Ser. No. 19

Imax = 164 mA



FM SOURCE

Ser. No. 20

Imax = 164 mA